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HEAVY MILITARY ELECTRONICS DEPARTMENT · SYRACUSE, N.Y.

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SECTION I

INTRODUCTION

Present implementation of the beamformer for the BQR-7 submarine sonar provides for stave-to-stave delays only. Consequently, it lacks the capability of steering or broadening the vertical beam by utilization of a time delay taper across the vertical dimension of the array. In essence, the array is optimized to receive target radiated noise through the surface duct mode. For short ranges between the target and the receiver, this gives satisfactory operation since most of the energy is in the surface duct.

At longer ranges, however, most of the energy may be propagated via the bottom bounce mode. This results in less than theoretically maximum performance for long ranges since the energy enters through the sidelobes of the vertical beam pattern. For targets of interest, the signal-to-noise ratio (SNR) at short ranges is high enough so that one might consider sacrificing some system gain at short ranges if the detection performance at longer ranges can be significantly improved.

There are several methods which might be utilized in upgrading the performance at long ranges. One method consists of steering the beam downward to intercept the energy arriving via the bottom bounce mode through the main beam of the vertical pattern. An alternate method consists of broadening the vertical beam pattern, without vertical steering, to intercept both bottom bounce and surface duct energy with the main beam. A third choice consists of a suitable combination of vertical steering and broadening to optimize the detection performance for all ranges.

A study was undertaken to investigate the various aspects of vertical beam steering and broadening and its effect on detection performance. An attempt was then made to verify the theoretical results by beamforming actual sea test data previously recorded at the hydrophone level aboard an SSB(N) 640 class submarine.

The feasibility of designing a compromise beamformer to handle numerous classes of submarines was also examined. Specifically, the classes of submarines examined were the SS(N) 594, SSB(N) 598, SSB(N) 608, and the SS(N) 671.

The results of the vertical beam coverage study as well as the compromise beamformer feasibility study are reported herein.

SECTION II

ASSUMPTIONS

1. DETECTION MODEL

The analytical model used to investigate the detection performance of the BQR-7 DIMUS beamformer calculates the SNR at the output of the detector. In general, the SNR at the output of a passive detection system is given by

$$\mathrm{SNR} = \frac{\left[\int_{f_1}^{f_2} P_s(f, R)\, df\right]^2}{\frac{1}{2T}\int_{f_1}^{f_2} P_n^2(f)\, df} \tag{1}$$

where

$P_s(f, R)$ = signal power spectrum at the input to the detector as a function of frequency (f) and range (R)

$P_n(f)$ = noise power spectrum at the input to the detector

T = the integration time of the output filter

f_1 = lower frequency limit of receiver operating band

f_2 = upper frequency limit of receiver operating band

The signal power spectrum at the input to the detector is calculated from the following expression:

$$P_s(f, R) = \sum_{i=1}^{N_P} \frac{L_T(f)\, N_{B_i}(f, R)\, T_R(f)\, Y(f)}{N_{W_i}(f, R)} \tag{2}$$

where

$L_T(f)$ = target radiated noise power

N_P = number of paths from the target to the receiver

$N_{B_i}(f, R)$ = vertical beam shape factor (the loss suffered by the signal arriving from the i^{th} path due to arrival off the main response axis of the array or due to beam broadening)

$T_R(f)$ = the transducer power response characteristic

$Y(f)$ = the pre-emphasis filter characteristic

$N_{W_i}(f, R)$ = the propagation loss for the i^{th} path from the target to the receiver

The noise power spectrum at the input to the detector, on the other hand, is given by:

$$P_n(f) = \frac{\left[L_{SN}(f) + L_{ON}(f)\right] T_R(f)\, Y(f)}{N_{DI}(f)} \tag{3}$$

where

$L_{SN}(f)$ = own ship's self-noise level

$L_{ON}(f)$ = ocean background level

$N_{DI}(f)$ = directivity index

A computer program has been developed to calculate the SNR as given in Equation (1). The program calculates the signal power spectrum and the noise power spectrum at discrete points within the receiver operating band by use of Equations (2) and (3). Equation (1) is then evaluated by numerical integration. The computations are repeated for each of the desired ranges.

Since the objective of the present study was to determine the effect of vertical beam broadening and depression, the previous computations were carried out under numerous combinations of vertical depression angle and vertical beam broadening. The effects of broadening can be accounted for by appropriate adjustment of the vertical beam shape factor.

The directivity index for the BQR-7 DIMUS utilized for the computations was taken from a rough draft copy of a memo (no title) issued by USNUSL, dated 31 July 1967. No change in directivity was assumed due to beam depression. However, adjustments were made in the vertical beam shape factor to account for the loss in directivity due to beam broadening.

The vertical beam shape factor was assumed to be that of a three-element line array (similar to the BQR-7 stave) having a 39-inch spacing between the elements. Broadening was accomplished by delaying the outer two elements equal amounts with respect to the center element, thus resulting in a vertical time delay taper which is an even function of element location. This results in a less coherent addition of signals arriving in the form of a plane wave along the vertical boresight, thereby producing a reduction in vertical directivity.

The propagation loss characteristics used for the study were those which are published in USNUSL Technical Memo 2111-020-67. The ocean model is the Norwegian Sea (during summer) having a depth of 2000 fathoms, a layer depth of 100 feet, and sea state of either 2 or 4. The spectral characteristics of the target model were also taken from this document.

2. THEORETICAL BEAM PATTERN

The theoretical beam pattern, as implied in this report, is the normalized plot of only that portion of the array output that is due to signal. It also includes the effects of timing errors.

If the instantaneous output of the array is considered as some voltage, the average value of the voltage squared is proportional to the average power out of the array. If the instantaneous output of the array is considered as some digital number, the average value of the number squared is the variance of the distribution of numbers out of the array. In either case, there will be some power (or variance) out of the array when no signal is present due to noise. The signal addition will cause this output power (or variance) to change. It is only this change in output which is of significance in the theoretical beam pattern.

For any fixed target strength, the change in output power will vary with the angle of arrival of the plane wave from the target. A three-dimensional plot of how this change in output varies with the angle of arrival, and normalized to a peak of unity, defines the theoretical beam pattern.

To define the theoretical beam pattern in mathematical terms, let

$f_i(t)$ = total output of element i at time t

T_i = applied time delay in output of element i

W_i = arbitrary weighting applied to output of element i

$f_o(t)$ = total output of array at time t

N = number of elements used in array

Since the array output is formed by adding the delayed outputs of each element, it follows that

$$f_o(t) = \sum_{i=1}^{N} W_i \, f_i(t - T_i) \tag{4}$$

The output of each element is composed of a noise portion, and a signal portion.

$f_{ni}(t)$ = noise portion of output of element i at time t

$f_{si}(t)$ = signal portion of output of element i at time t

then

$$f_i(t) = f_{si}(t) + f_{ni}(t) \tag{5}$$

Consider some hypothetical omnidirectional element located at an arbitrary reference point. Let

$f_s(t)$ = output of hypothetical reference element at time t due to a plane wave signal from a distant point source target

t_i = transit time of plane wave front from reference point to element i

w_i = relative response of element i compared to hypothetical standard; w_i can be made a function of angle of arrival to account for element directivity

From the above definitions, it follows that

$$f_{si}(t) = w_i\, f_s(t - t_i) \tag{6}$$

Squaring Equation (4), taking the average value, and combining with Equations (5) and (6) leads to the average variance (or power) out of the array

$$\sigma_o^2 = \overline{f_o^2(t)} = \sum_{i=1}^{N}\sum_{j=1}^{N} \overline{W_i W_j \left[w_i f_s(t - t_i - T_i) + f_{ni}(t - T_i)\right] \left[w_j f_s(t - t_j - T_j) + f_{nj}(t - T_j)\right]} \tag{7}$$

A bar over a quantity indicates time average and is assumed to be the same as an ensemble average.

Since the signal and noise are independent of each other, the average value of cross product terms between signal and noise in Equation (7) is zero. Equation (7) thus simplifies to

$$\sigma_o^2 = \sum_{i=1}^{N}\sum_{j=1}^{N} (W_i\, w_i)(W_j\, w_j)\ \overline{f_s(t - t_i - T_i)\, f_s(t - t_j - T_j)}$$
$$+ \overline{W_i\, W_j\, f_{ni}(t - T_i)\, f_{nj}(t - T_j)}$$

Notice that the first term in the above accounts only for signal, while the second is only noise. In keeping with the definition of the theoretical beam pattern presented earlier, interest lies only in the signal portion of this output.

The time delays T_i are chosen such that when the signal is on boresight, $T_i = -t_i$. On boresight then, the time averaged quantity reduces to $\overline{f_s^2(t)}$. Normalizing the signal portion of Equation (8) to this peak value on boresight and recognizing the normalized autocorrelation function of the signal as indicated in Equation (9) leads to Equation (10).

$$\rho_s(-t_i - T_i + t_j + T_j) = \frac{\overline{f_s(t - t_i - T_i)\, f_s(t - t_j - T_j)}}{\overline{f_s^2(t)}} \tag{9}$$

$$p = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} (W_i\, w_i)(W_j\, w_j)\ \rho\ (-t_i - T_i + t_j + T_j)}{\sum_{i=1}^{N}\sum_{j=1}^{N} (W_i\, w_i)(W_j\, w_j)} \tag{10}$$

where

p = theoretical beam pattern of linear beamformer

Finding the argument of the autocorrelation coefficient in terms of the geometry of the array still remains. Let

$\vec{r}_i$ = vector from the arbitrarily chosen reference point for the hypothetical standard transducer discussed above to element i

c = magnitude of the velocity of propagation of the plane wave front (signal)

$\vec{c}$ = unit vector in the direction of propagation of the plane wave front

Using conventional notation for a vector dot product, it follows that the transit time from the reference point to element i is

$$t_i = \left(\frac{1}{c}\right) \vec{r}_i \cdot \vec{c} \tag{11}$$

Let

$\vec{s}$ = unit vector in the direction chosen for boresight

It follows from the definition of $\vec{c}$ and $\vec{s}$ that when a target is on boresight, vectors $\vec{c}$ and $\vec{s}$ coincide. Consequently, the exact time delay required for beamforming is the negative of the transit time given by Equation (11) when $\vec{c}$ is replaced by $\vec{s}$.

The applied time delay (T_i) may deviate slightly from this ideal value due to quantizing errors. The error in time delay actually used will then be given by

$$e_i = -\left[T_i + \left(\frac{1}{c}\right) \vec{r}_i \cdot \vec{s} \right] \tag{12}$$

The argument of the autocorrelation coefficient in Equation (10) can now be found by combining Equations (11) and (12) and factoring. Thus

$$(-t_i - T_i + t_j + T_j) = \left(\frac{1}{c}\right) (\vec{r}_i - \vec{r}_j) \cdot (\vec{s} - \vec{c}) + (e_i - e_j) \tag{13}$$

Notice that this argument is independent of the arbitrarily chosen origin. It depends only on the vector distance between elements i and j, and the difference between boresight and the actual angle of arrival.

Equations (10) and (13) give the desired theoretical beam pattern by letting the vector $\vec{c}$ scan through the region of interest. Arbitrary spectra are accounted for by appropriately specifying the normalized autocorrelation function ρ_s. If the power density spectral distribution of a signal is known, its autocorrelation function can be derived by a Fourier transform relationship. Element directivity, amplitude weighting to shape beams, and opaque arrays can be accounted for by the factors $W_i\ w_i$. (These are unity for omnidirectional elements in a transparent array.) Errors in timing are accounted for by e_i.

When computing the theoretical beam patterns, it has been assumed that the element directivity is unity, and that the amplitude weighting is uniform. Timing errors which are included in the theoretical beam patterns are due to two sources. One type of timing error is caused by time delay quantization. The second type of error results from using a single compromise set of time delays for two or more classes of submarines.

SECTION III

RESULTS

1. VERTICAL BEAM COVERAGE STUDY

a. Theoretical Results

One of the objectives of this study was to determine whether the detectability of targets could be improved by depressing or broadening the vertical beam. However, the term "detectability" is arbitrary since there is no clear cut definition of what is required to constitute a target detection. The approach which was taken here was to calculate the SNR at the detector output. This performance measure can then, at least in theory, be related to the probability of detection. Calculation of the probability of detection, however, is not considered within the scope of this report.

The computer program which has been developed calculates the SNR for a given input target range. The set of target ranges which was utilized is 1.0, 1.6, 2.5, 4.0, 6.3, 8.0, 10.0, 16.0, 25.0, 40.0, and 50.0 kiloyards. This choice of ranges was used since the propagation loss data for these parameters has been published. To present the computer output in a useful format for the present study, the SNR was calculated for these ranges at 1° increments in vertical steering angle ranging from 0 through 45° depression angle. The data was then linearly interpolated to determine the contours of constant SNR on a vertical depression angle versus range plot.

Numerous inputs are required in order to calculate the signal power spectrum and the noise power spectrum. For this purpose it was assumed that the input signal spectrum was weighted by the present BQR-7 pre-emphasis filter and that the power response characteristic of the transducer was uniform. Furthermore, the own ship's self-noise level was modeled after the SSB(N) 616 platform moving at a speed of five knots.

All SNR contour plots shown in this section of the report are evaluated on the basis of an output filter integration time of 0.5 second. In other words, the term $\frac{1}{2T}$ in the denominator of Equation (1) has been set equal to unity. If a filter integration time other than 0.5 second is used, the SNR is theoretically shifted by $10 \log_{10} (2T)$. If an integration time of 12.8 seconds is used, as is anticipated for the BQR-7 DIMUS, the SNR curve is shifted by about 14 dB.

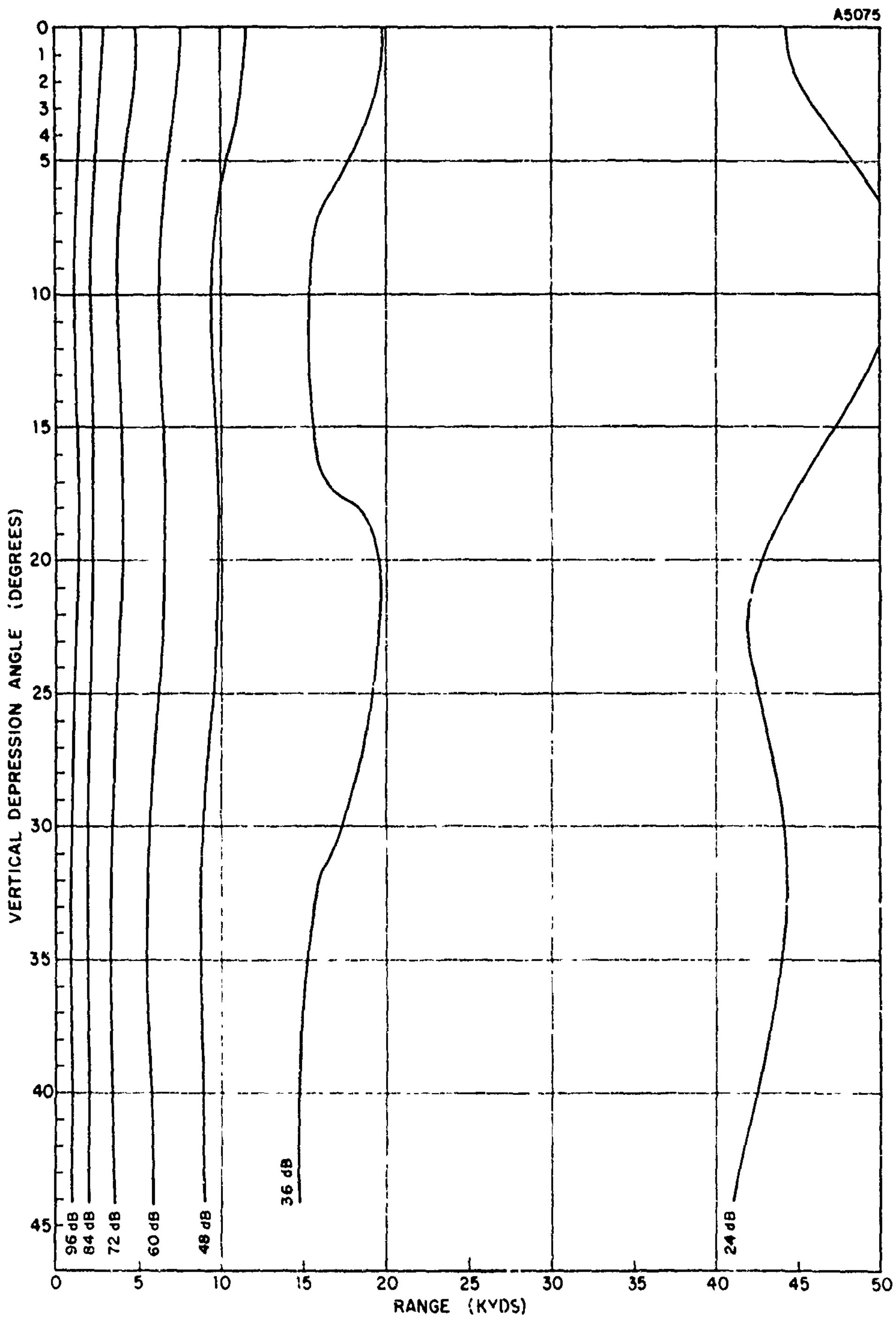

Figure 1. SNR Contours for a 10-Knot Snorkler with Target and Receiver on Same Side of Layer

Three target models for which the spectral characteristics were available were used to calculate the signal power spectrum. These were a 10-knot snorkler, a Skipjack [SS(N) 585], and a Permit [SS(N) 594] submarine. Figures 1 through 3 are the respective SNR contour plots for these three targets in the absence of vertical beam broadening. The results for these plots are based on the assumption that the target and the receiver are located on the same side of the layer. The plots are repeated in Figures 4 through 6 for the case where the target and the receiver are located on opposite sides of the layer. Sea state 2 is assumed in each case.

As expected, the high SNR contours decrease in range as the vertical beam is depressed. This occurs since the energy in the surface duct (which is the primary propagation mode at short range) enters the system off the main response axis of the vertical beam pattern. For noisy targets such as the 10-knot snorkler, a definite range improvement is noted by depressing the vertical beam by 9 or 10°. It should be emphasized that this improvement is totally due to the fact that the target is extremely noisy and that the signal energy in the bottom bounce propagation mode is sufficient to yield a high SNR at long ranges. The results indicate that the 24-dB contour extends beyond the 50-kyd range for an integration time of 0.5 second regardless of whether the target and receiver are located on the same or opposite sides of the layer. With an integration time of 12.8 seconds each of the contours shown is theoretically improved by an additional 14 dB.

For quiet targets such as the Permit submarine, an improvement in range is not so obvious. It tends to be limited by the assumptions with respect to the environment, directivity, and the improvement resulting from an increased integration time. If there is no loss in the vertical directivity due to depressing the beam and the full 14 dB of SNR improvement is realized by the BQR-7 DIMUS 12.8 seconds integration time, the 0-dB contour would fall between the present -12 and -18 dB contour in Figure 3. This would then result in improved range performance for the 0-dB contour if the beam were depressed 10 to 15°. It should be emphasized however, that if in practice the SNR improvement is closer to 6 dB, then the 0-dB contour gives considerably worse range performance than it would if the vertical beam had not been depressed at all. The same general conclusions can be made with respect to the case where the target and the receiver are situated on opposite sides of the layer (see Figure 6). If the theoretical improvement due to time averaging 12.8 seconds could be achieved, the best 0-dB range contour would be obtained by depressing the beam between 20 and 25°.

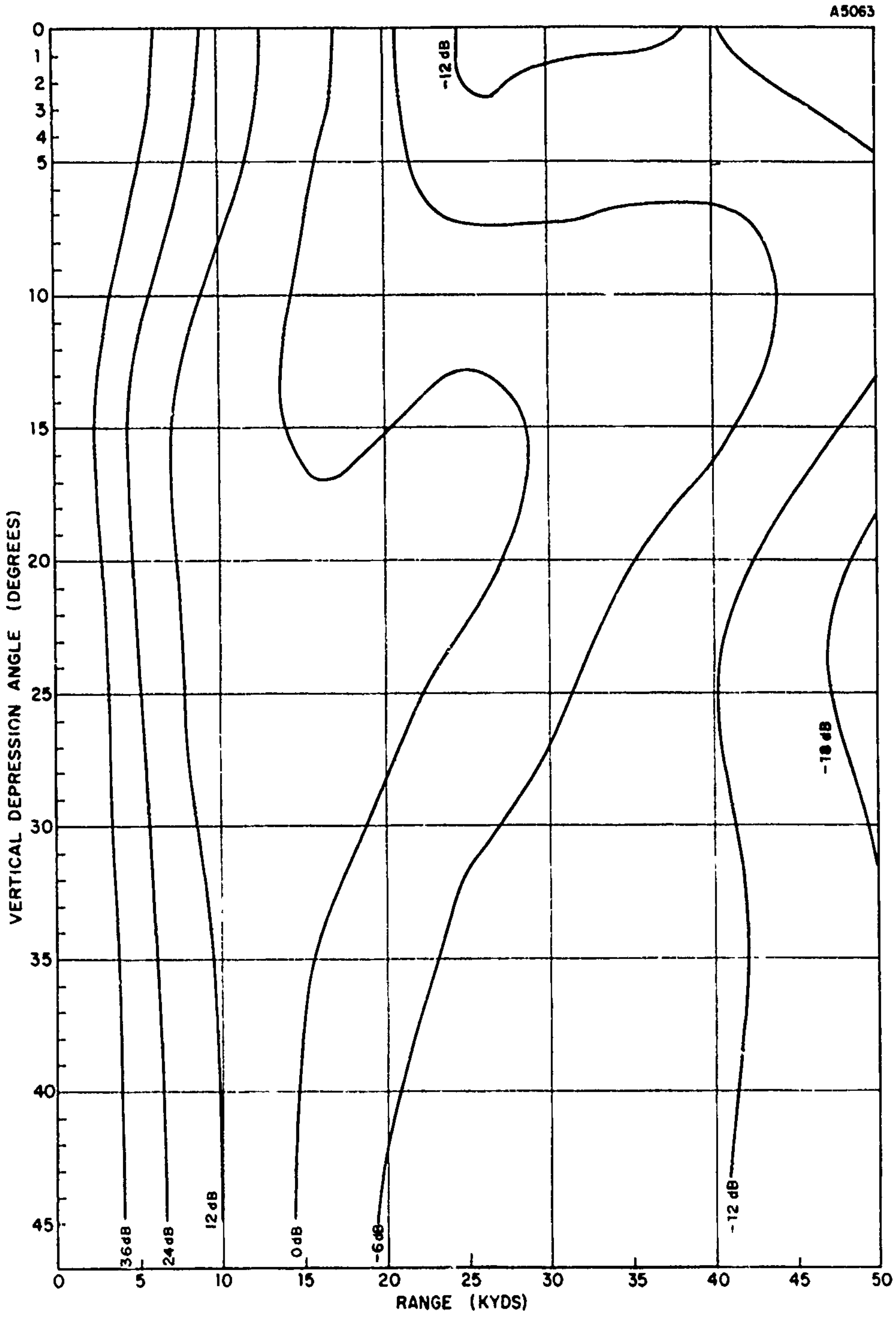

Figure 2. SNR Contours for a Skipjack Submarine with Target and Receiver on Same Side of Layer

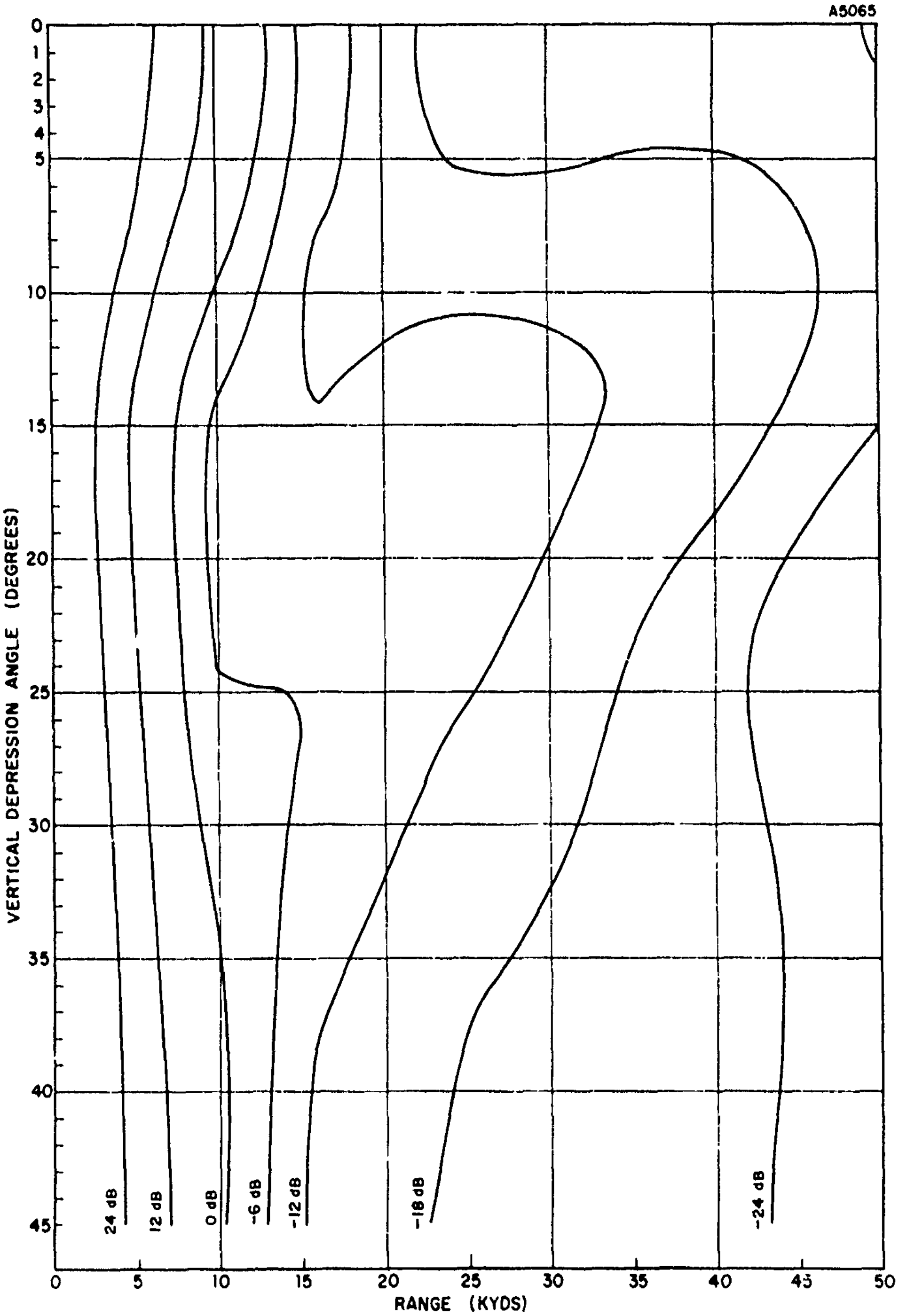

Figure 3. SNR Contours for a Permit Submarine with Target and Receiver on Same Side of Layer

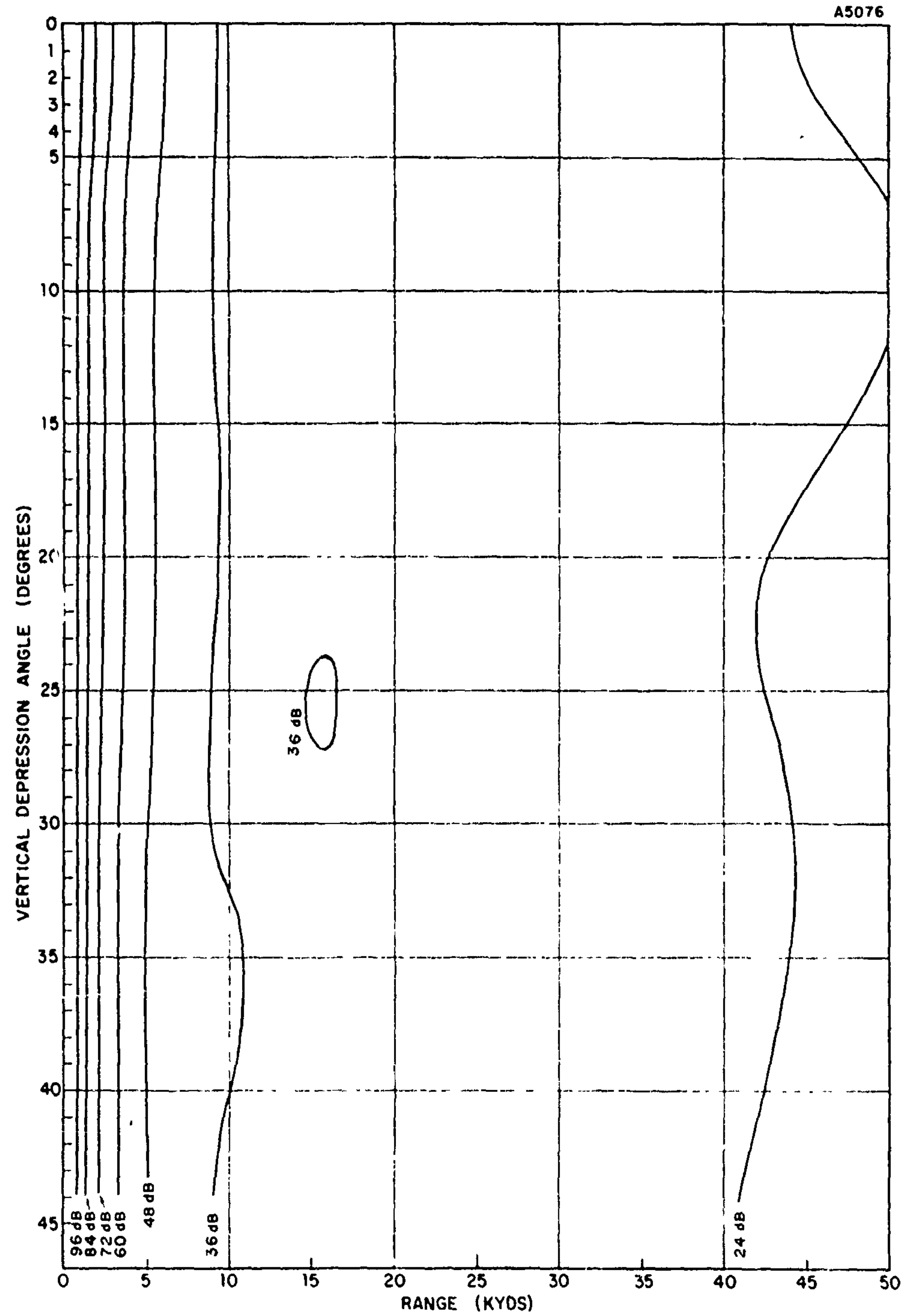

Figure 4. SNR Contours for a 10-Knot Snorkler with Target and Receiver on Opposite Sides of Layer

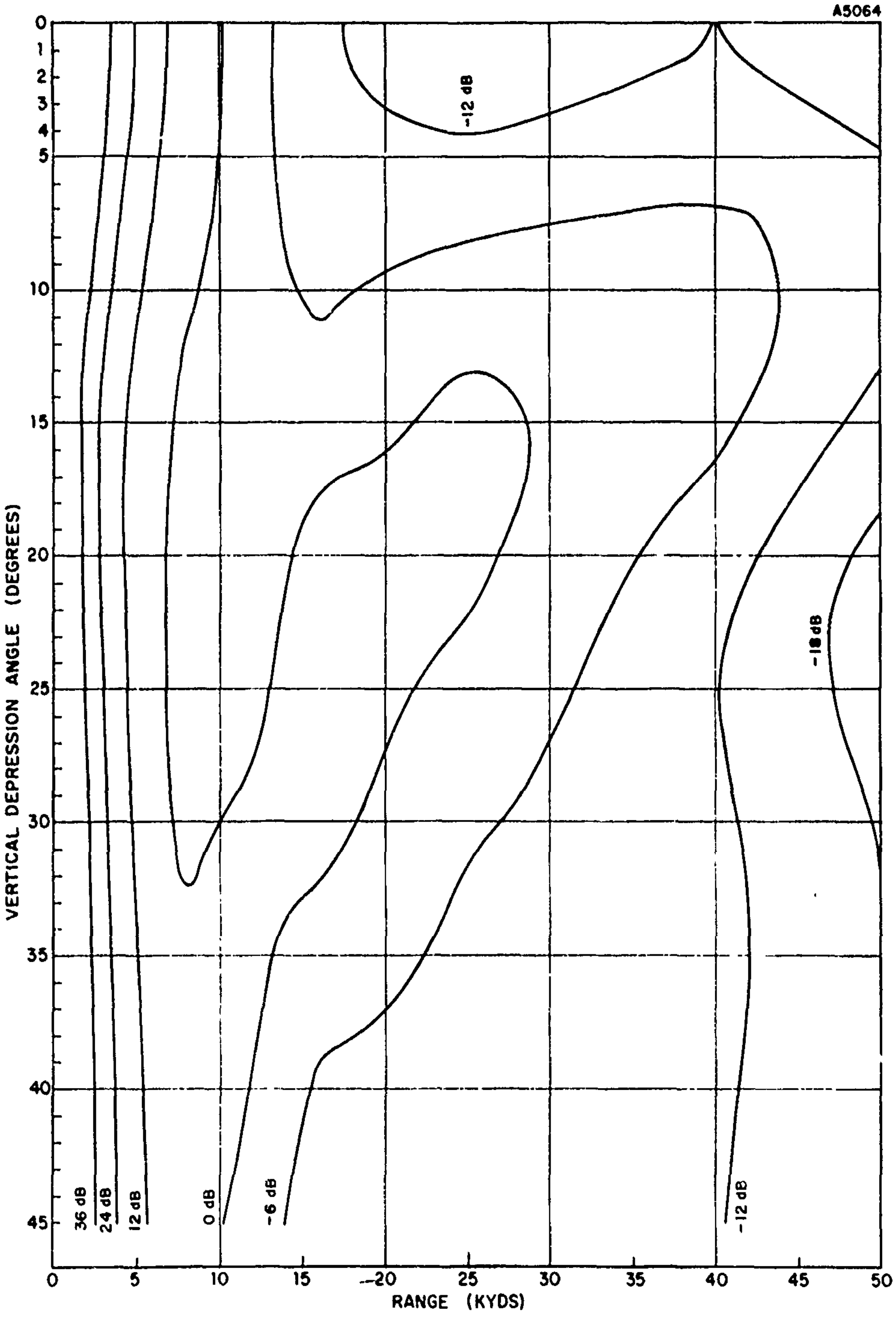

Figure 5. SNR Contours for a Skipjack Submarine with Target and Receiver on Opposite Sides of Layer

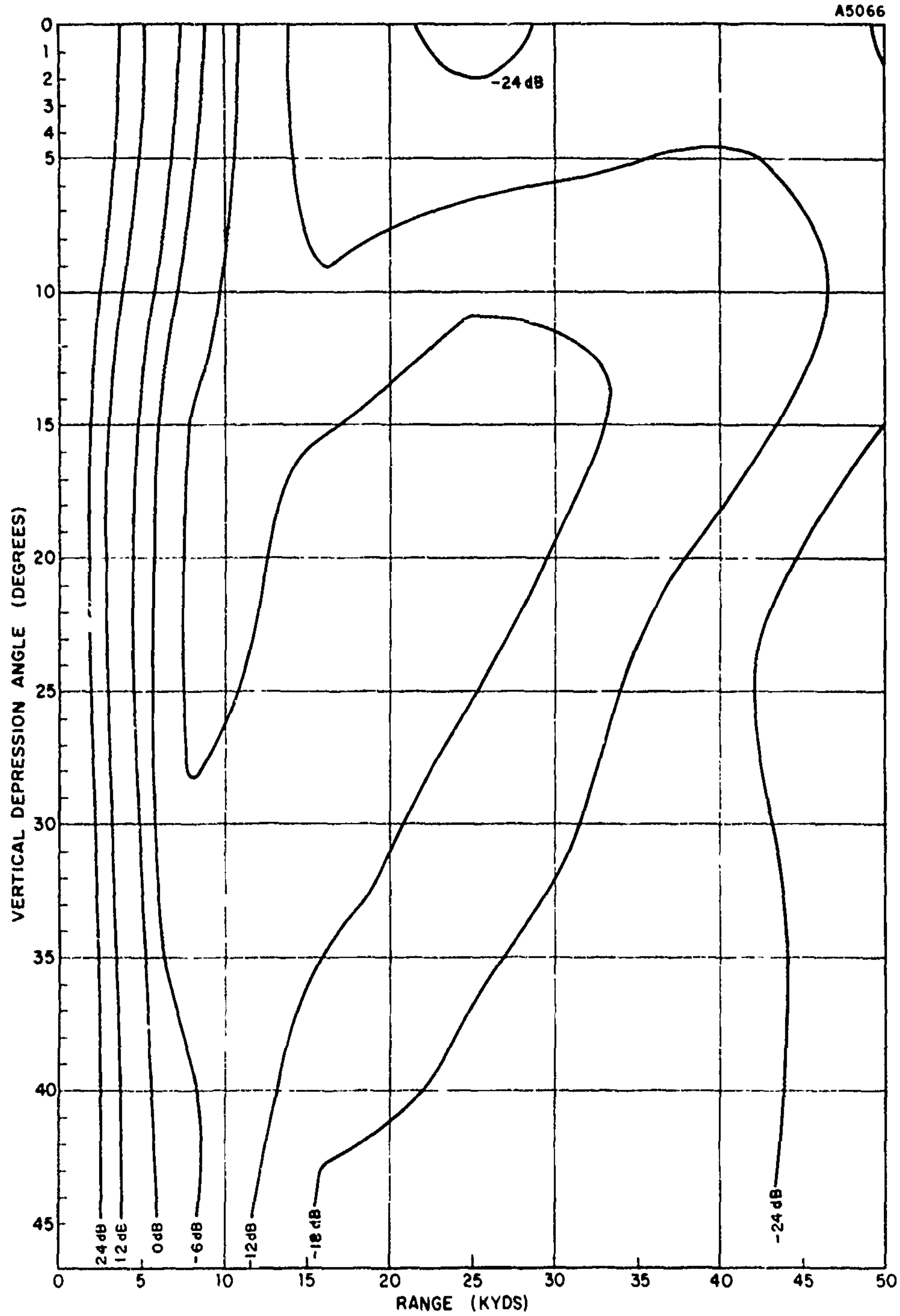

Figure 6. SNR Contours for a Permit Submarine with Target and Receiver on Opposite Sides of Layer

SNR contour plots including the effects of vertical beam broadening using the Permit submarine for target radiated noise were computed. This target model was chosen since it has the least favorable (quietest) characteristics for detection. Before presenting the results, a few comments are in order to clarify the method used to achieve the vertical beam broadening.

Computerized implementation of vertical beam broadening was accomplished by appropriate adjustment of the vertical beam shape factor of Equation (2). The vertical beam pattern was assumed to be independent of the horizontal steering angle. Furthermore, the vertical pattern was assumed to be equivalent to that of a three-element line array. Broadening was achieved by delaying the outer two elements by equal amounts. Originally it was intended to accomplish beam broadening by computing the applied time delays on the basis of an erroneous velocity of sound which is higher than that experienced at sea. Since it was more feasible however, from the standpoint of existing computer programs to implement the broadening procedure as outlined above, the former approach was selected. This method also has the flexibility of varying the depression angle and the broadening independently.

To illustrate that vertical beam broadening can be achieved by use of this method, the vertical beam patterns for the BQR-7 array were calculated using various amounts of delay for the upper and lower layers (or rows) of elements. The results are shown in Figures 7 through 13. Each of these figures shows the vertical beam pattern for seven specific beams. Beams 1 through 3 are directed toward the stern of the ship, Beam 12 is directed toward the port side, and Beams 29 through 31 are directed forward. Note that a separate abscissa is drawn for each beam. Each beam is normalized so that the 0-dB point represents completely coherent addition of the input signal (a theoretical maximum). Any loss is therefore caused by the time delay errors required for broadening or time delay errors due to quantization. Ticks are drawn at 3-dB intervals from the peak response of each beam.

Figure 7 represents the vertical patterns without broadening. Figures 8 through 13 indicate the results obtained by applying delays up to 375 μs in steps of 62.5 μs. Note specifically how the beam is broadened by increasing amounts of delay. Further note that broadening is accompanied by a noticeable reduction in gain along boresight.

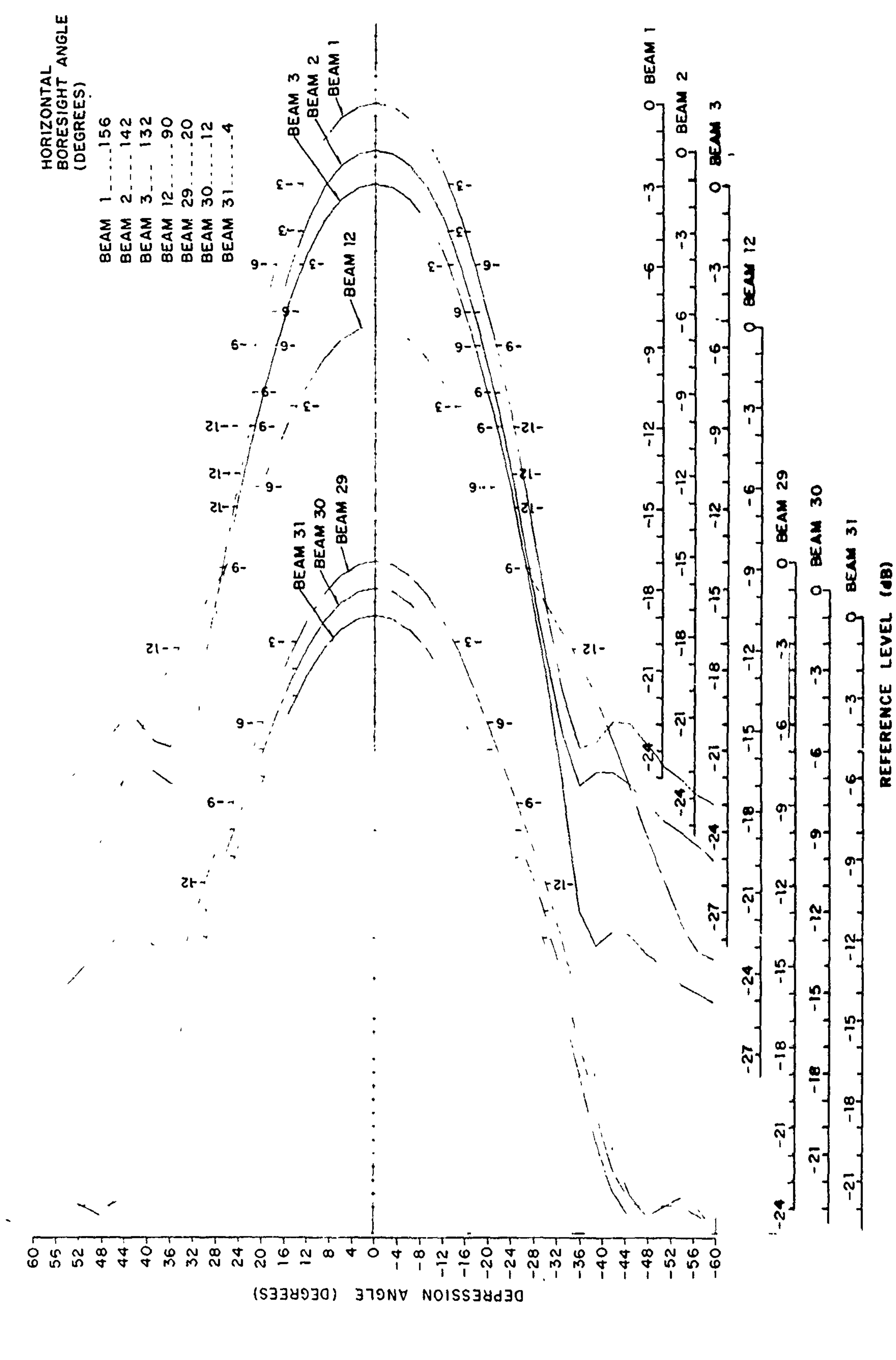

Figure 7. Vertical Beam Patterns Without Broadening

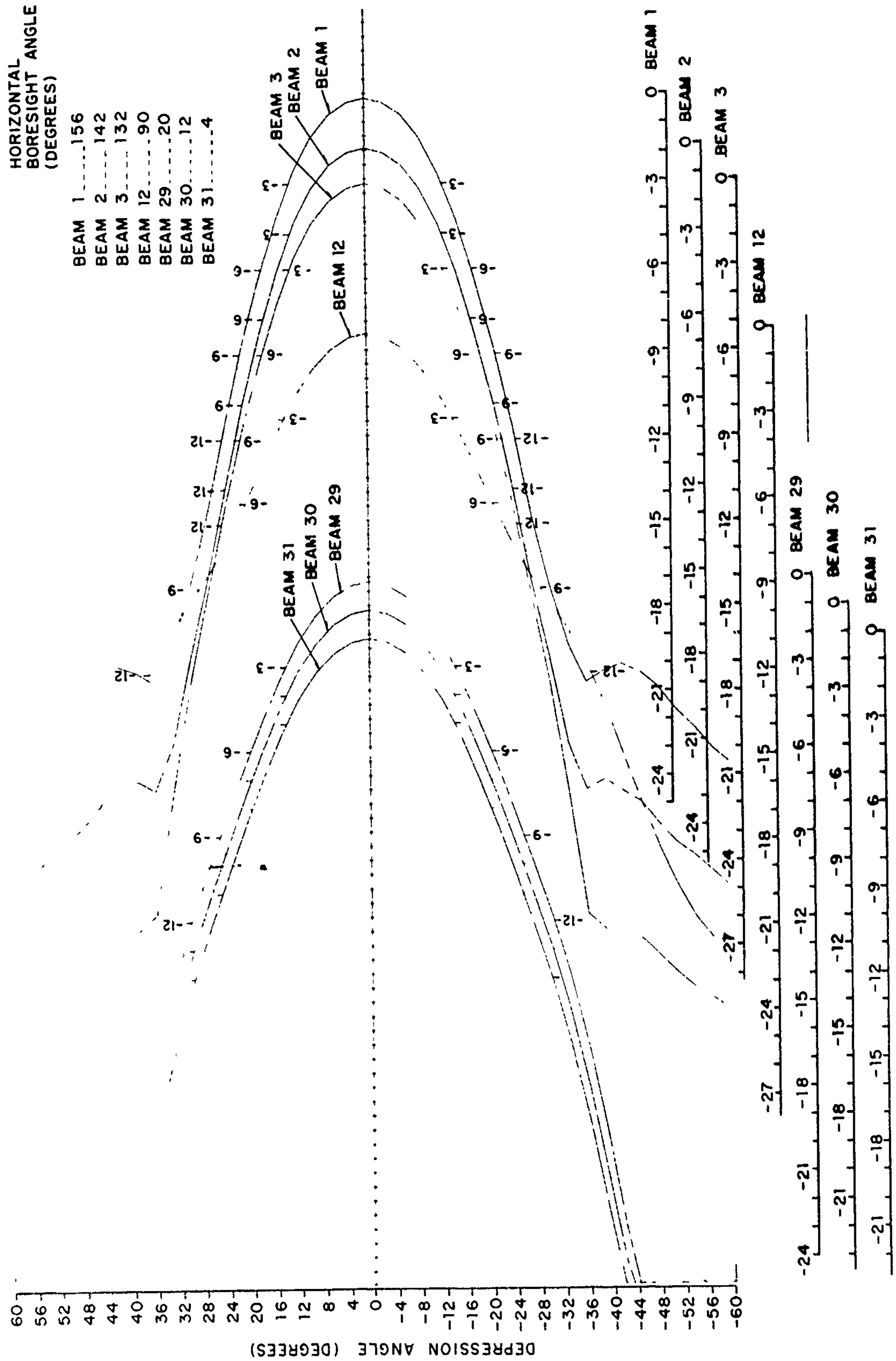

Figure 8. Vertical Beam Patterns Obtained by Delaying Upper and Lower Rows of Elements by 62.5 μs

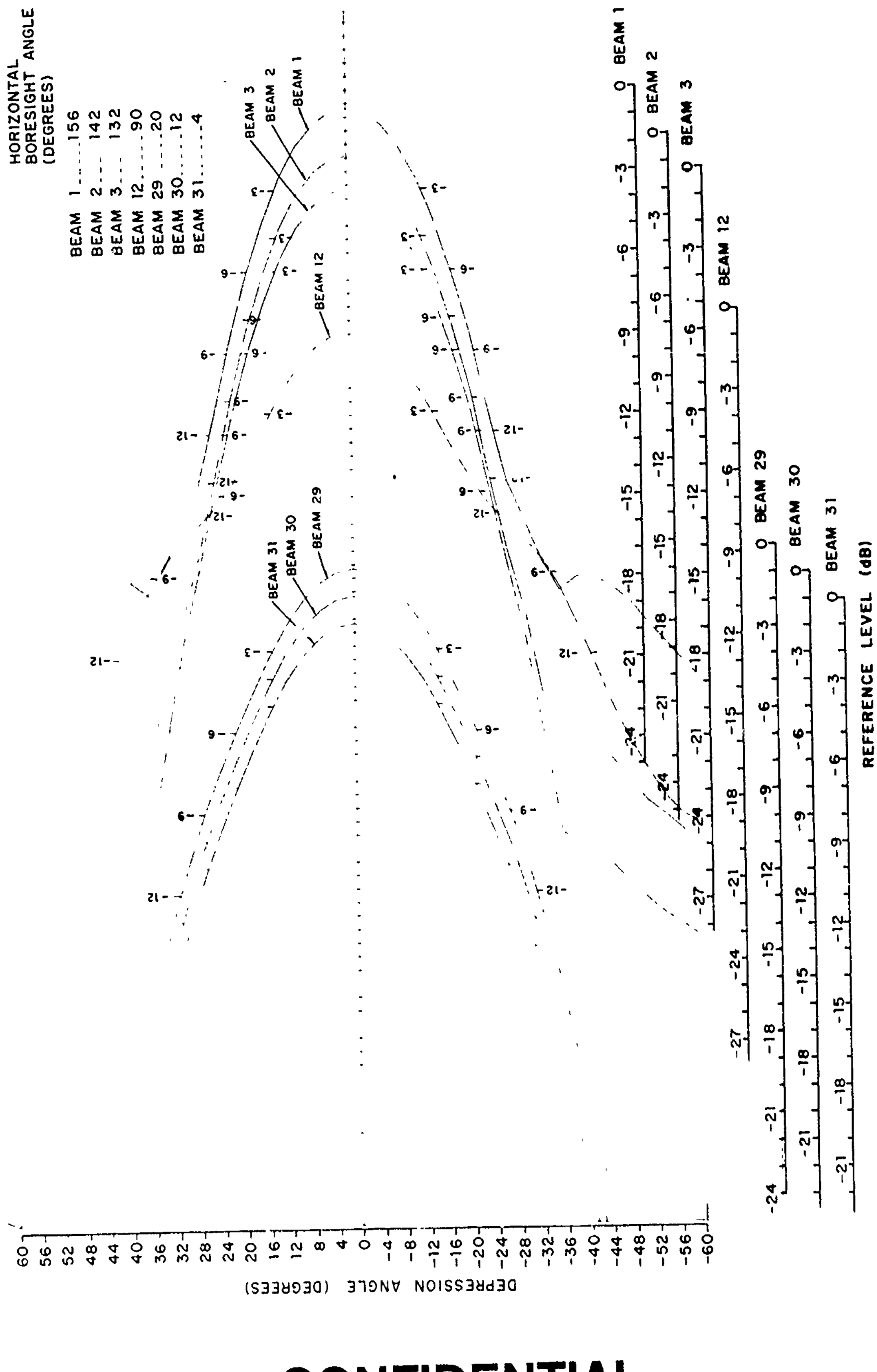

Figure 9. Vertical Beam Patterns Obtained by Delaying Upper and Lower Rows of Elements by 125 μs

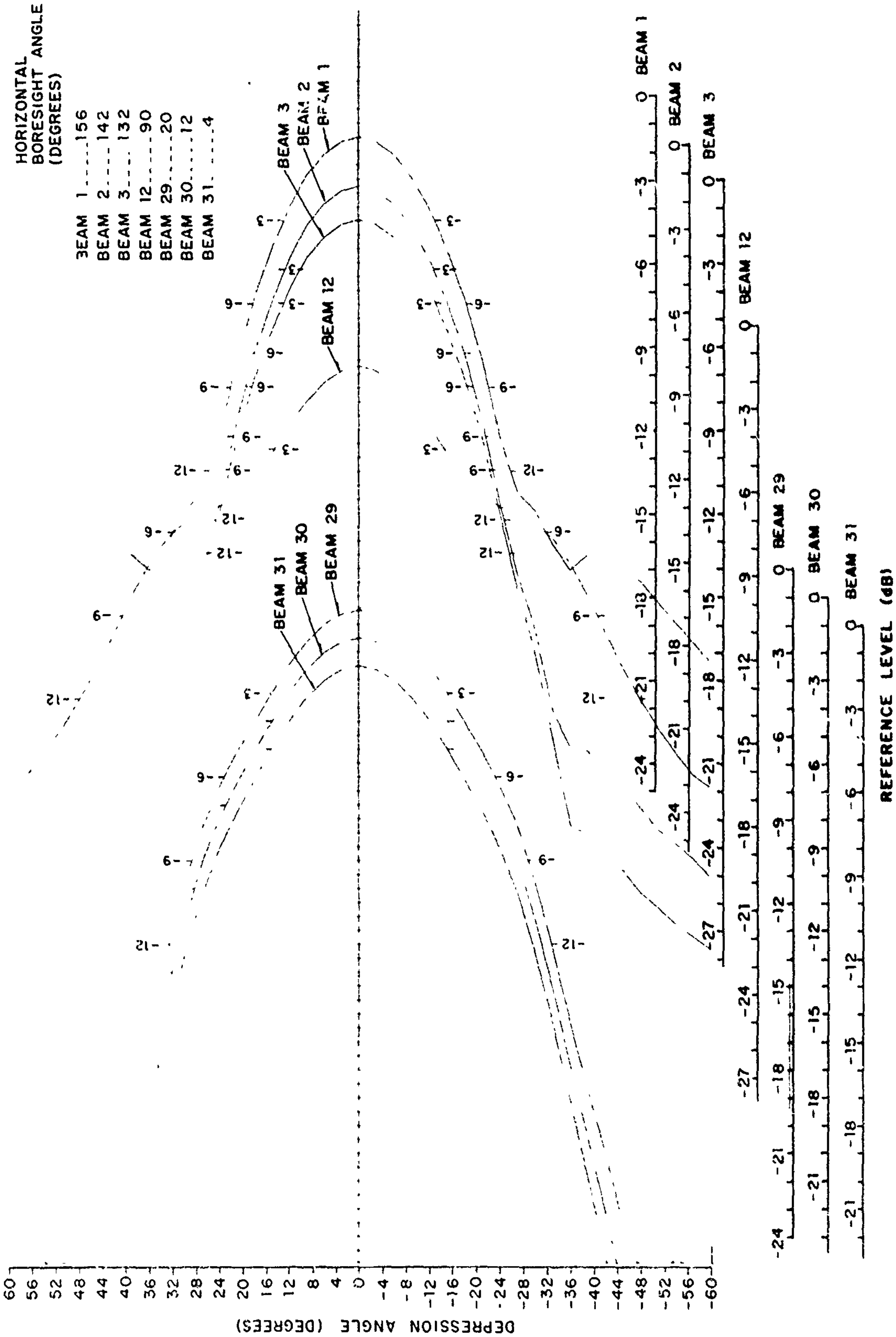

Figure 10. Vertical Beam Patterns Obtained by Delaying Upper and Lower Rows of Elements by 187.5 μs

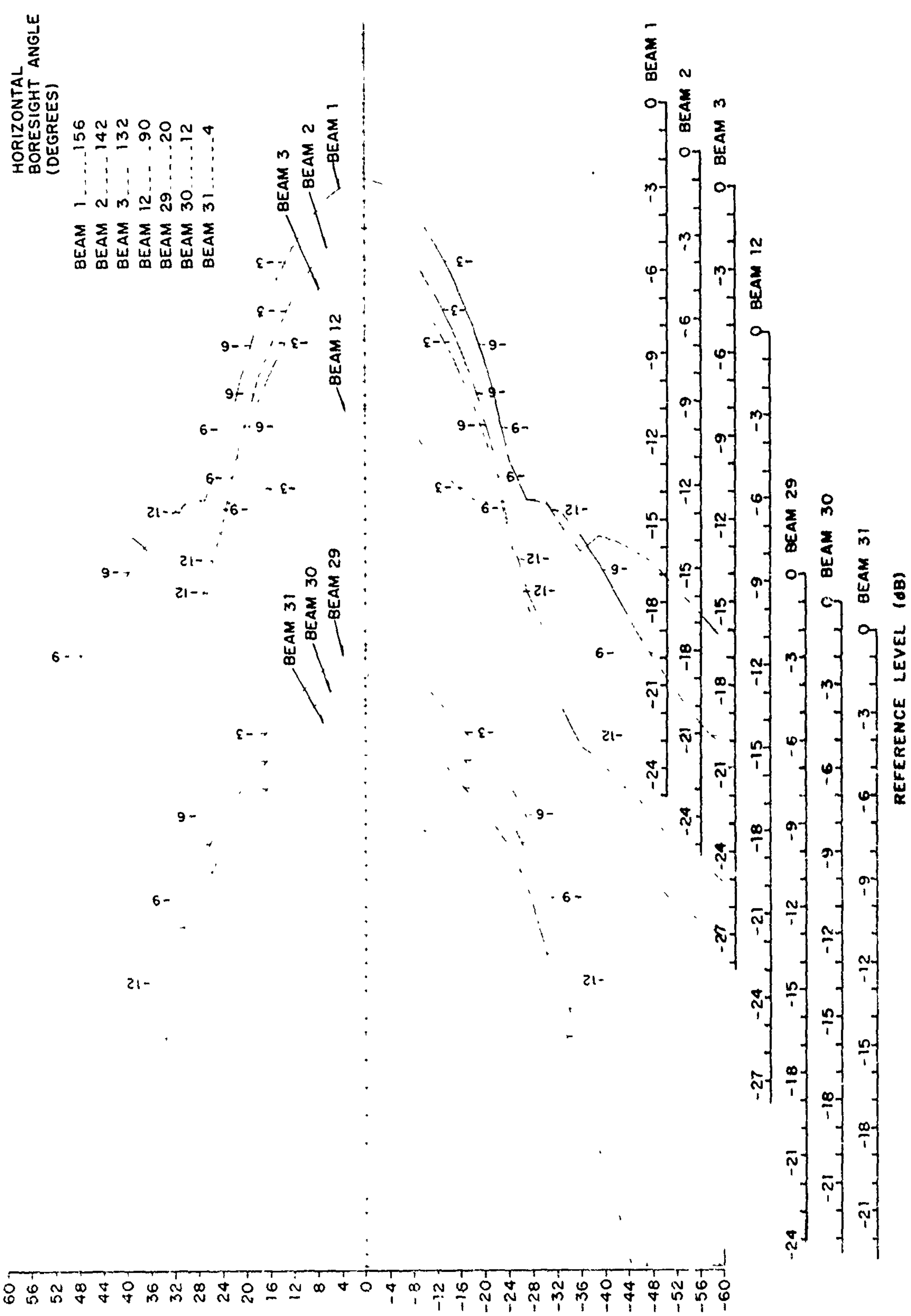

Figure 11. Vertical Beam Patterns Obtained by Delaying Upper and Lower Rows of Elements by 250 μs

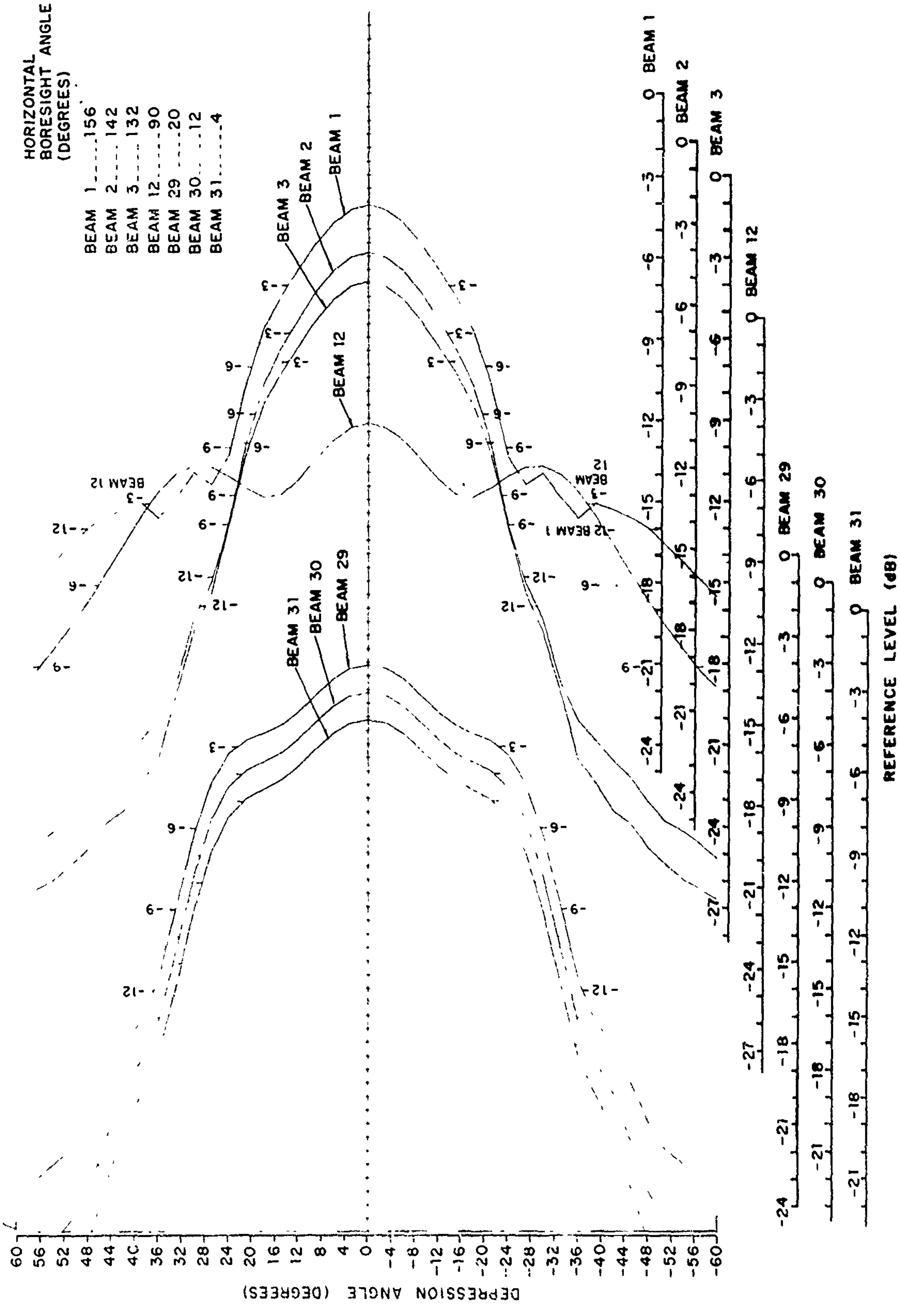

Figure 12. Vertical Beam Patterns Obtained by Delaying Upper and Lower Rows of Elements by 312.5 μs

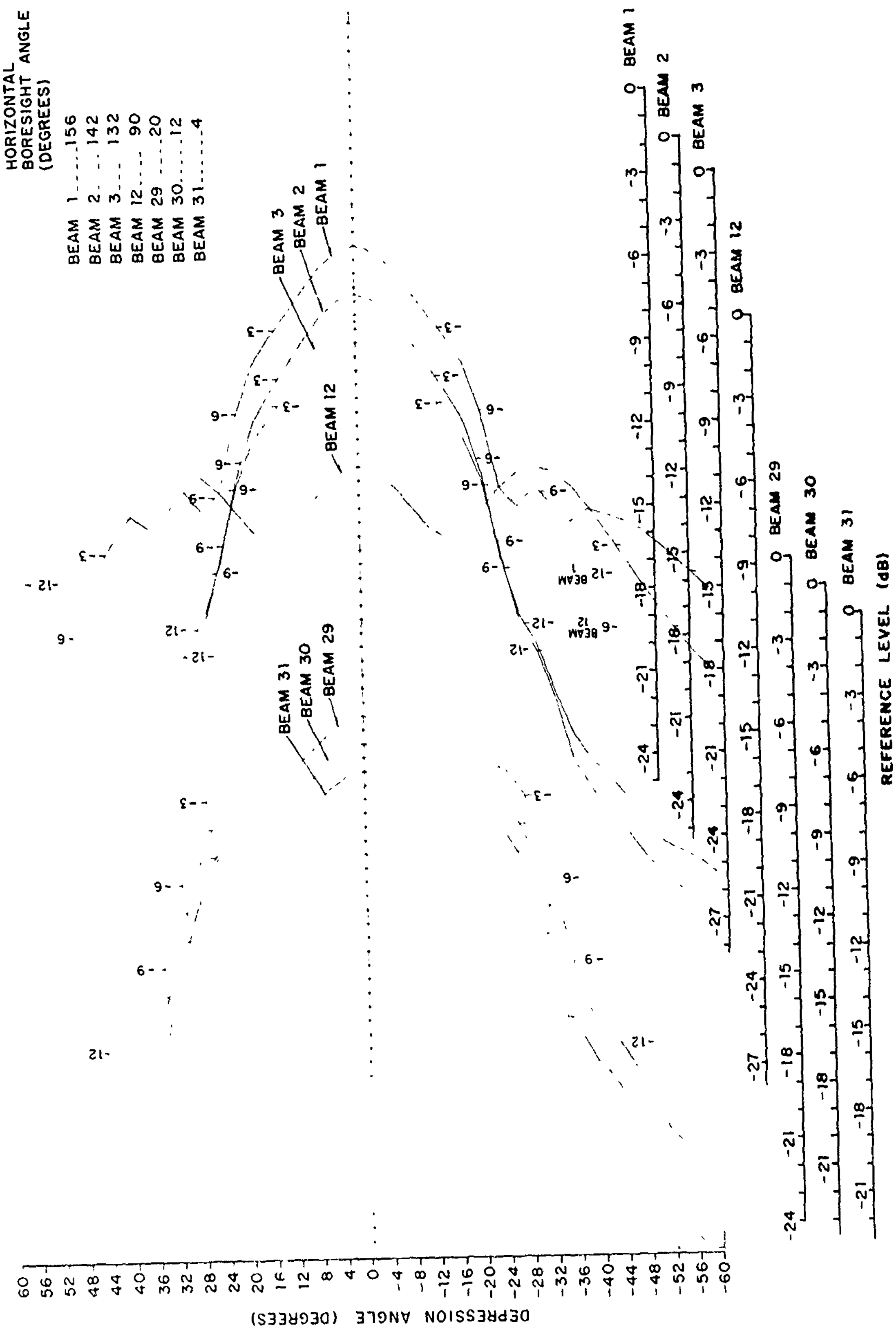

Figure 13. Vertical Beam Patterns Obtained by Delaying Upper and Lower Rows of Elements by 375 μs

Figures 14 through 16 are the SNR contours for various amounts of broadening with the target and receiver on the same side of the layer. Figure 14 indicates the results obtained by applying a 62.5-μs delay to each of the outer elements of the stave while Figures 15 and 16 are the results for applying 125- and 187.5-μs delays, respectively. Figures 17 through 19 indicate the results for identical amounts of broadening but with the target and receiver on opposite sides of the layer.

The particular delays chosen to implement vertical beam broadening for the SNR contours were selected to give a specified amount of phase shift between the outer and center elements. The resulting phase shifts at the band center frequency are $\frac{\pi}{8}$, $\frac{\pi}{4}$, and $\frac{3\pi}{8}$ radians.

One observes the same trends for broadening as were observed for depression only. Low SNR contours show improved range performance. The range improvement for low SNR contours is achieved however at the expense of reduced performance at higher SNR contours. The detectability of quiet targets, such as the Permit, at shorter ranges has been impaired.

Figures 20 and 21 show the results for a Permit target, no vertical beam broadening and sea state 4. Note from these curves that even if a 12-dB improvement were achieved through integration, beam depression would result in lower ranges for the 0-dB SNR contour.

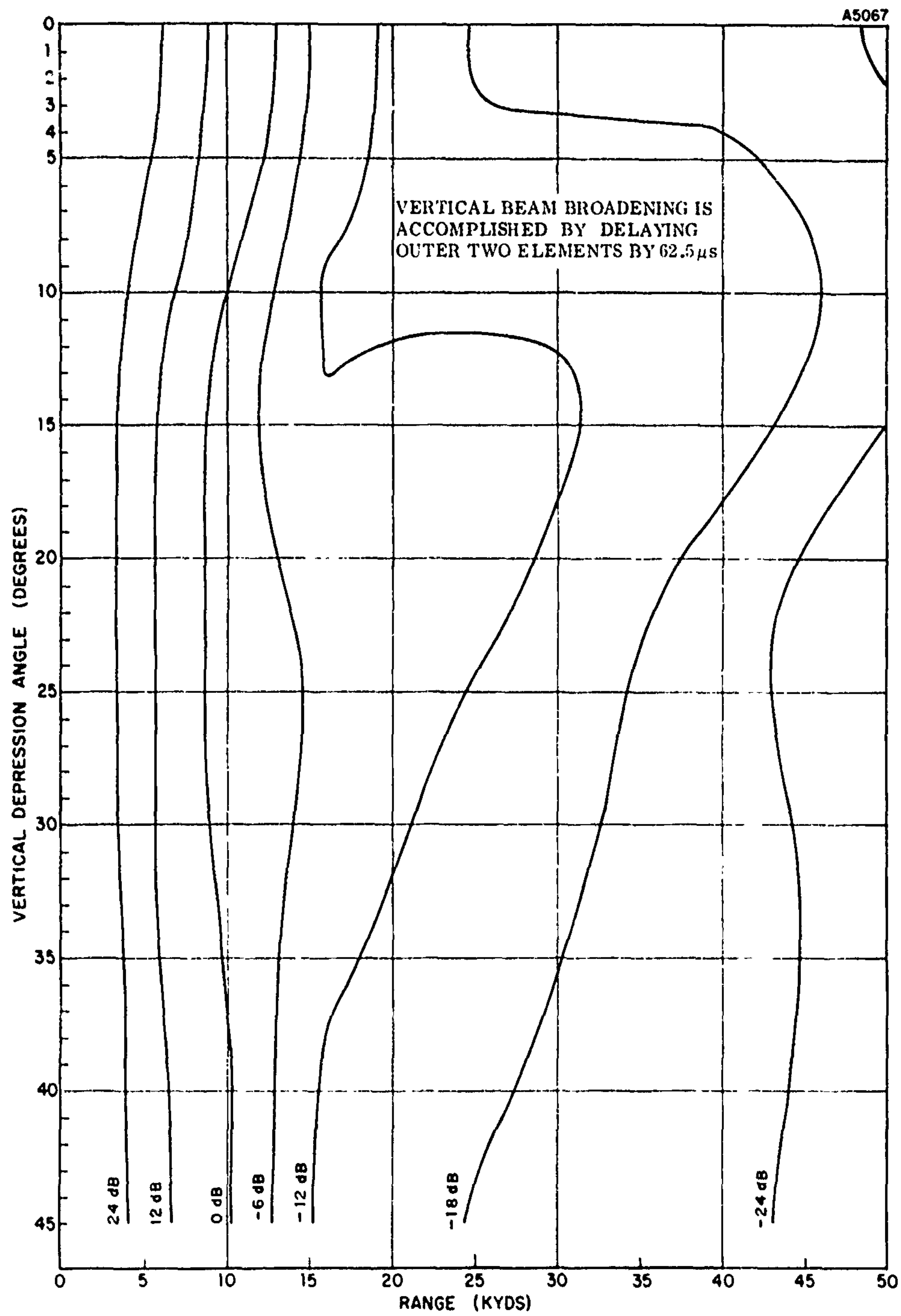

Figure 14. SNR Contours with Vertical Beam Broadening for Permit Submarine with Target and Receiver on Same Side of Layer

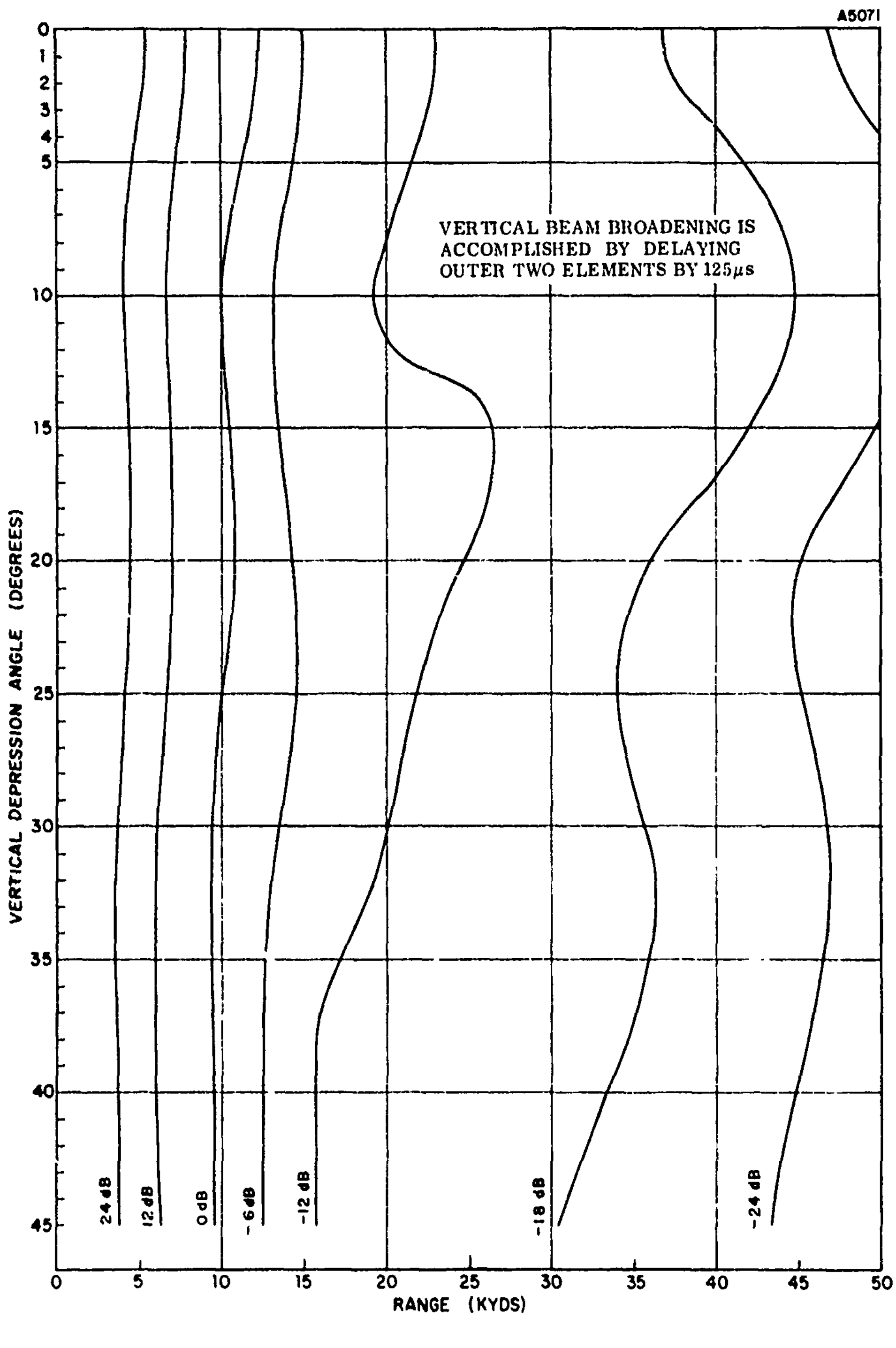

Figure 15. SNR Contours with Vertical Beam Broadening for Permit Submarine with Target and Receiver on Same Side of Layer

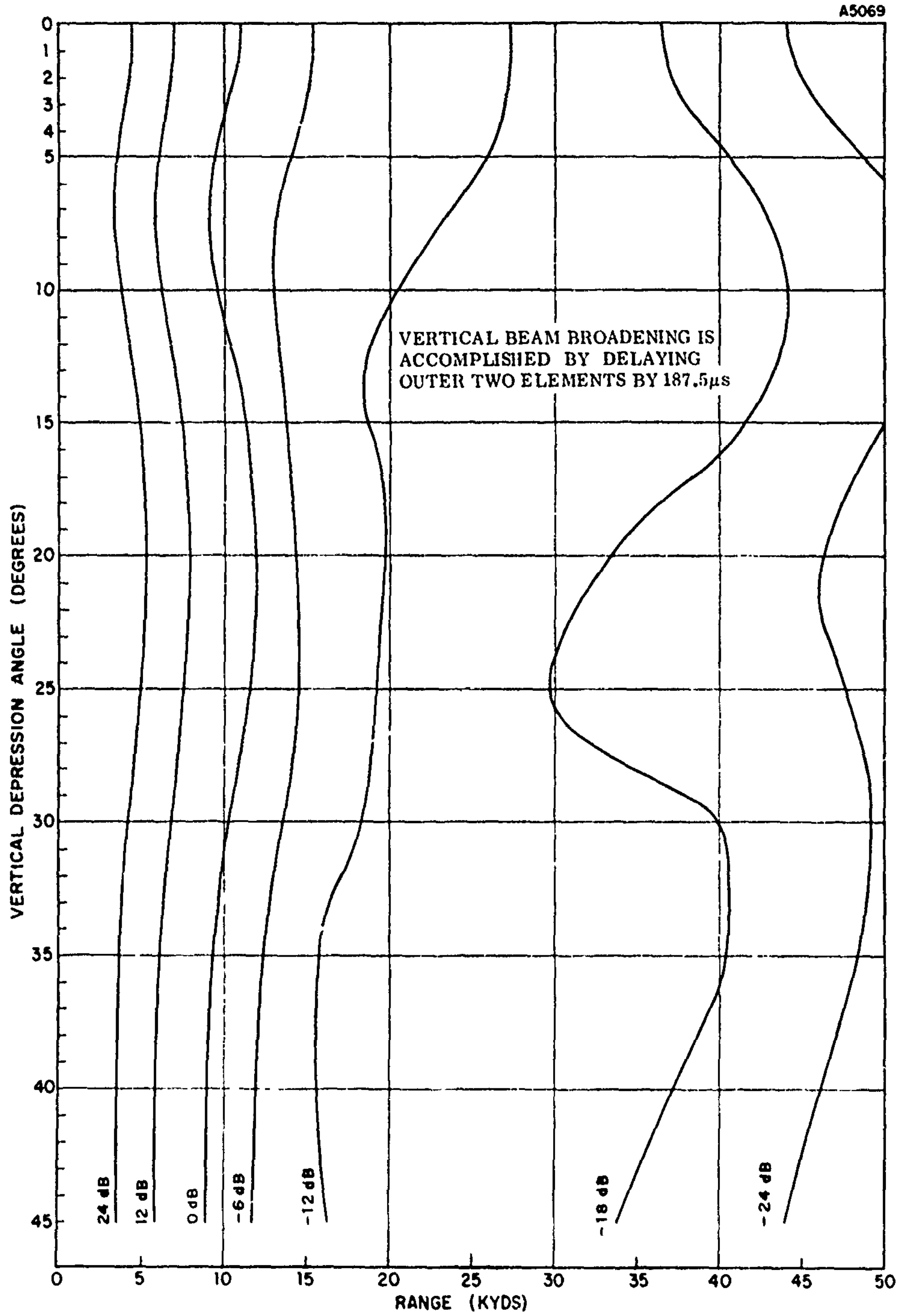

Figure 16. SNR Contours with Vertical Beam Broadening for Permit Submarine with Target and Receiver on Same Side of Layer

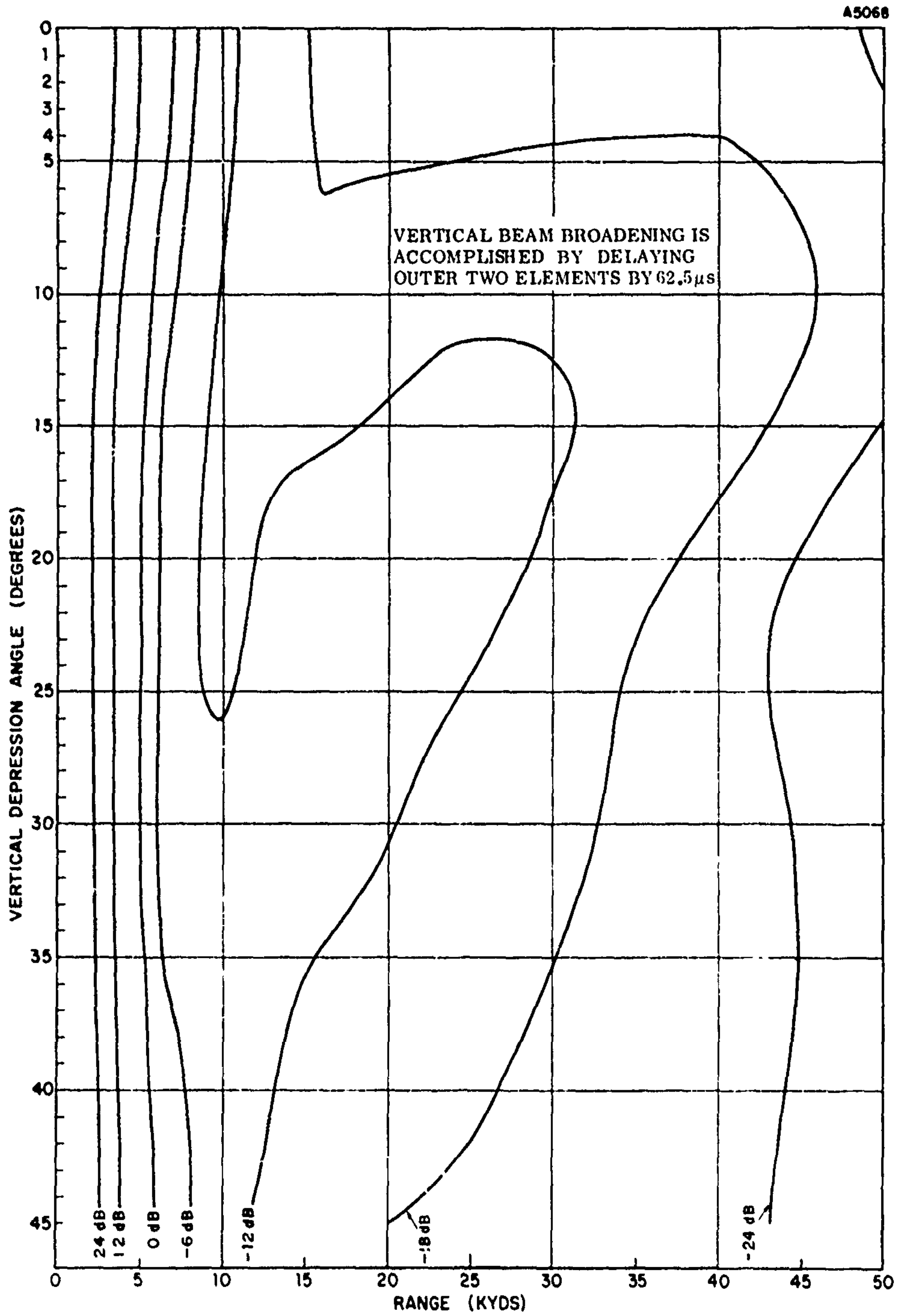

Figure 17. SNR Contours with Vertical Beam Broadening for Permit Submarine with Target and Receiver on Opposite Sides of Layer

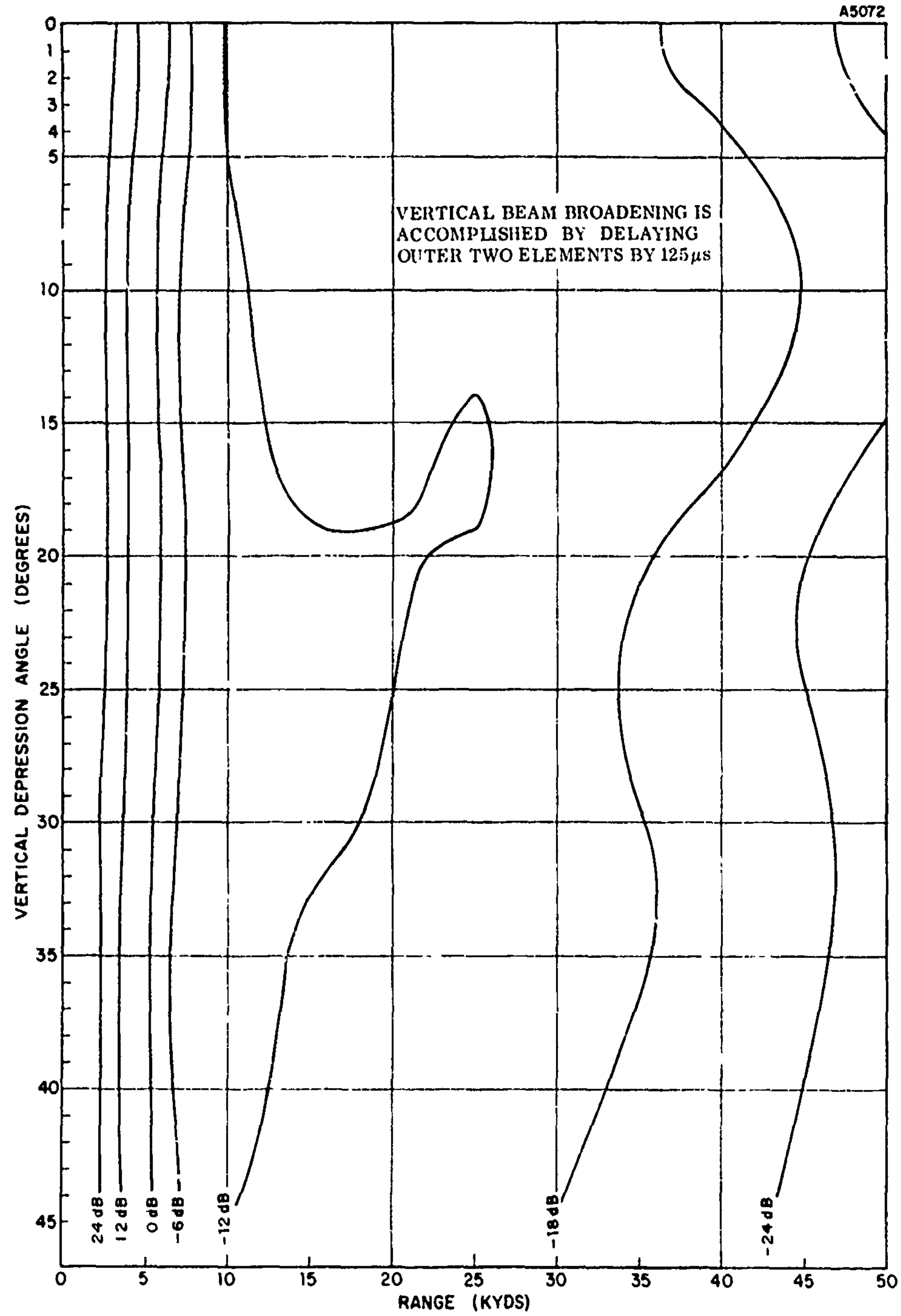

Figure 18. SNR Contours with Vertical Beam Broadening for Permit Submarine with Target and Receiver on Opposite Sides of Layer

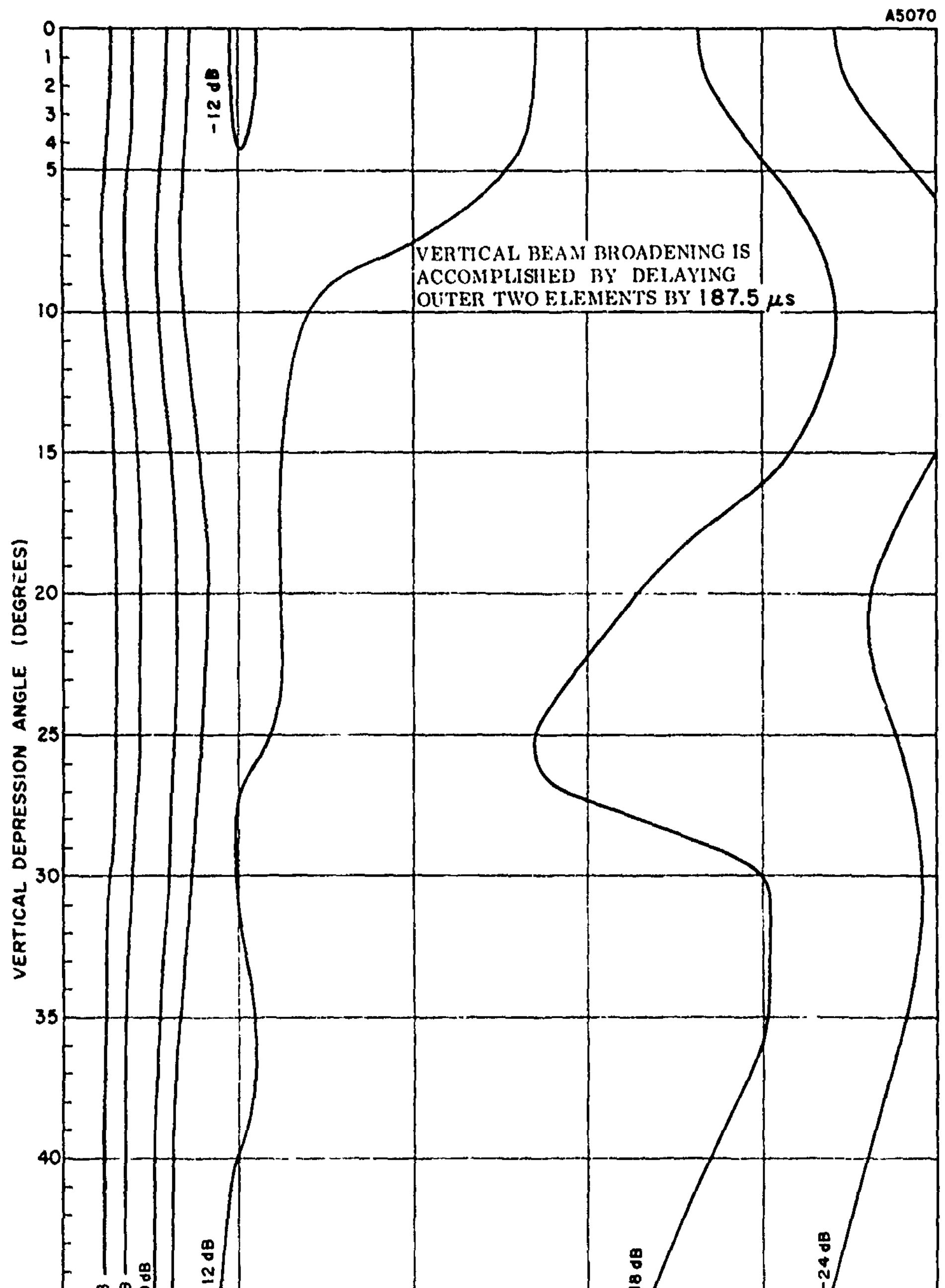

Figure 19. SNR Contours with Vertical Beam Broadening for Permit Submarine with Target and Receiver on Opposite Sides of Layer

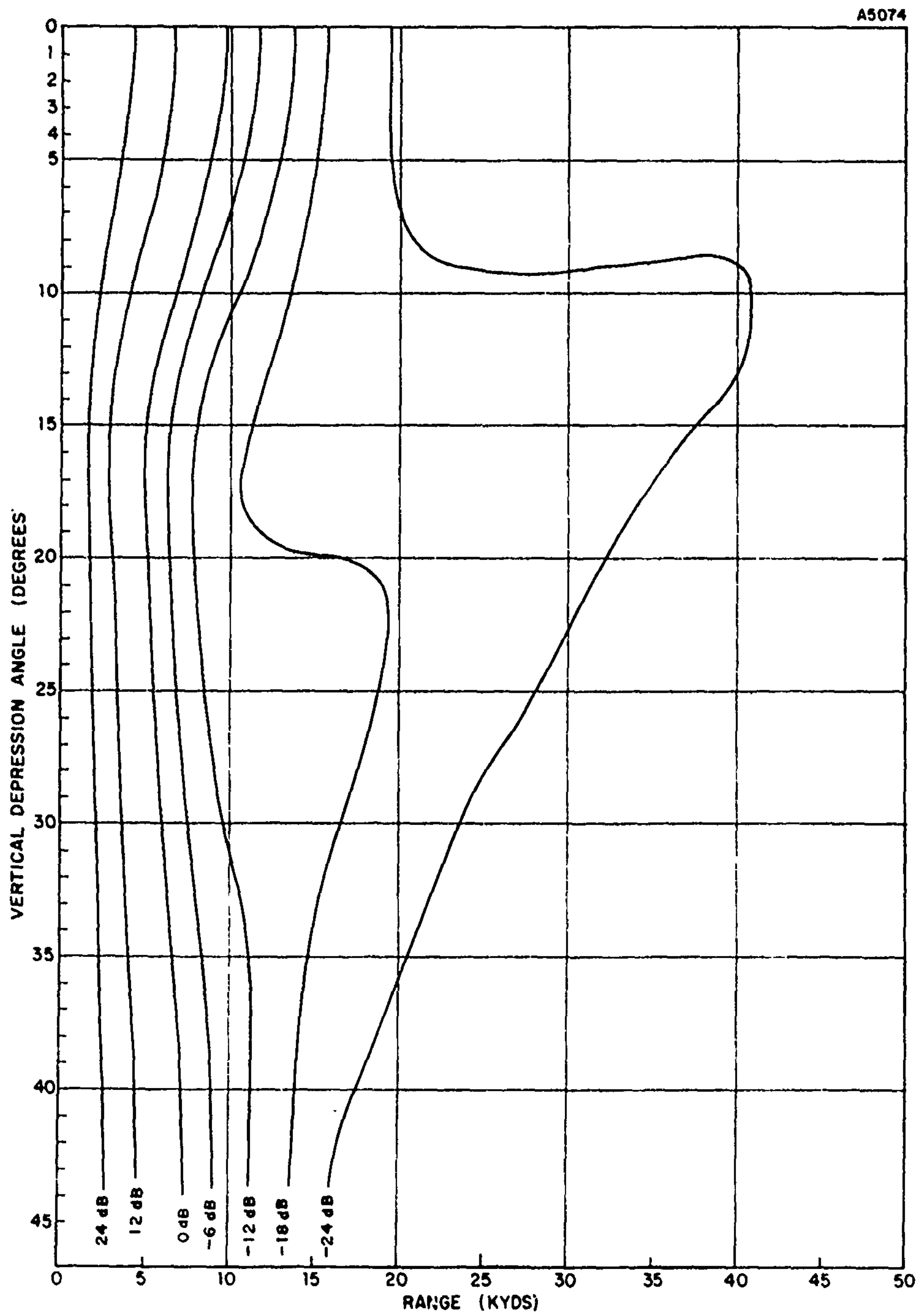

Figure 20. SNR Contours for a Permit Submarine with Target and Receiver on Same Side of Layer with Sea State 4

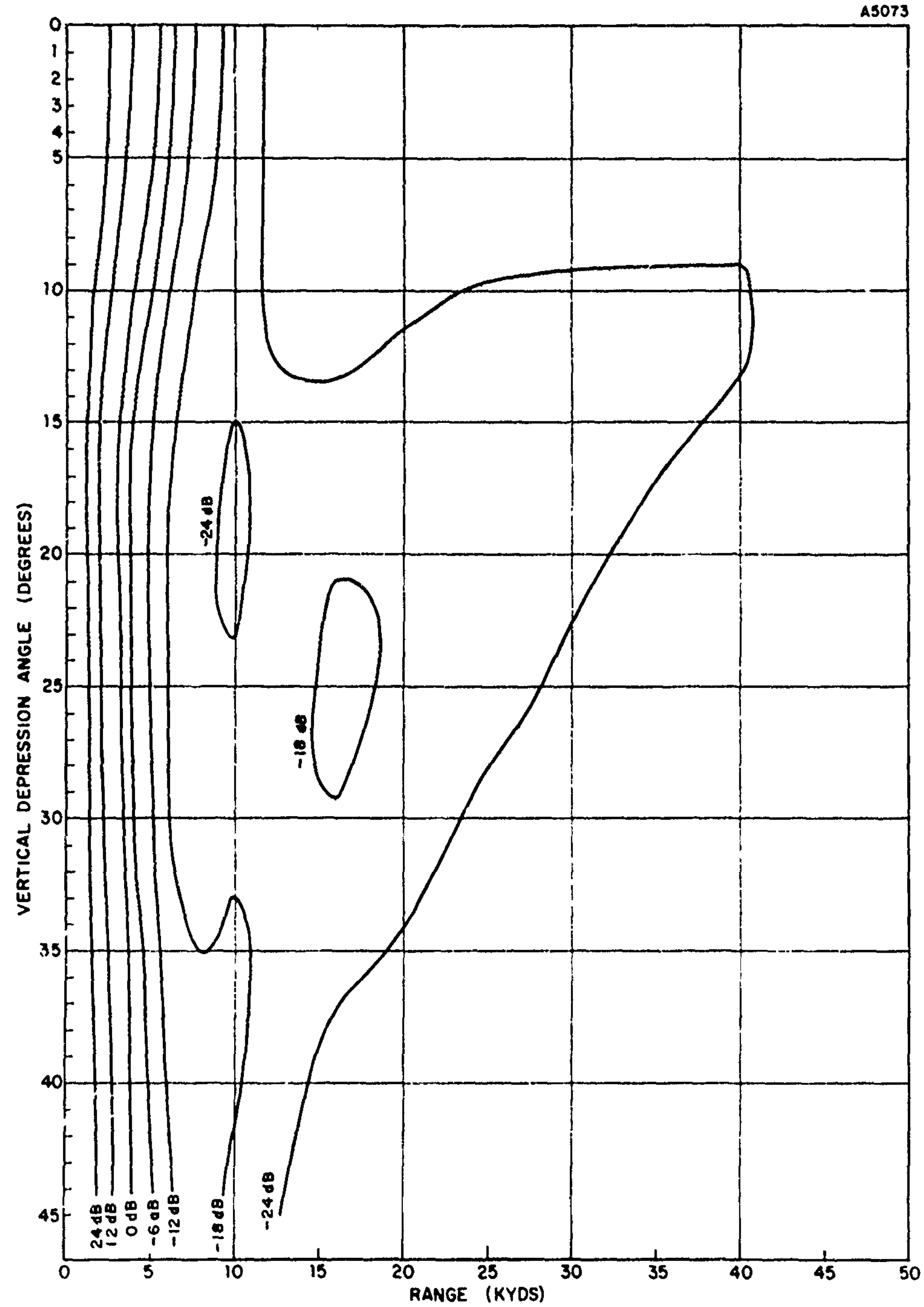

Figure 21. SNR Contours for a Permit Suomarine with Target and Receiver on Opposite Sides of Layer with Sea State 4

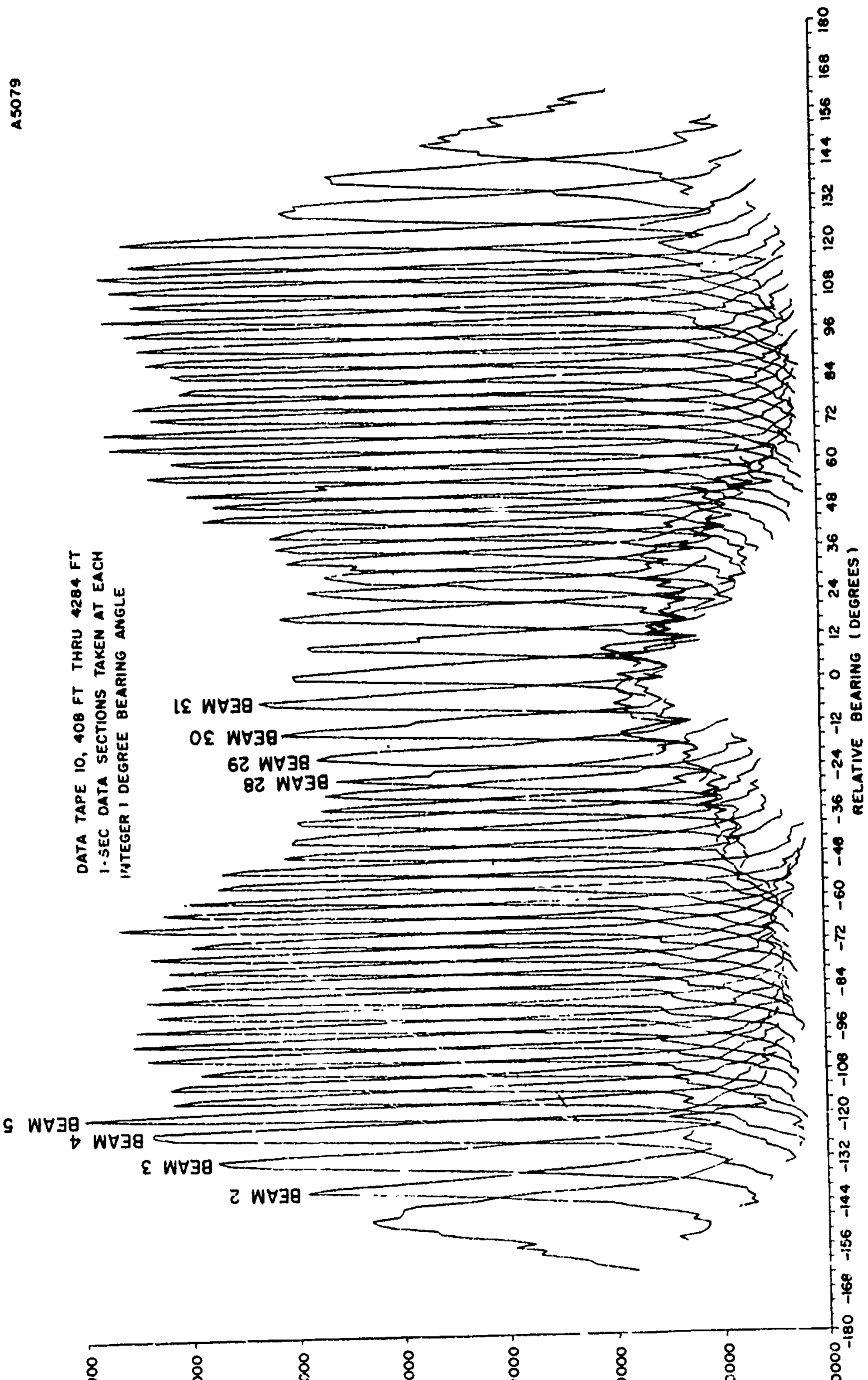

Figure 22. BQR-7 DIMUS Beamformer Correlation Patterns Based on a Sound Velocity of 5120 Feet per Second

b. Results from Sea Test Data

An attempt was made to verify the theoretical results by beamforming taped data recorded at sea. The tape is a recording of the BQR-7 preamplifier outputs aboard the SSB(N) 657, Francis Scott Key. The USS Angler served as the target ship. Although Key was on her first exercise following commissioning, the performance of her sonar appeared to be excellent.

Tape No. 10 was utilized for the present experimental verification, and taken while Angler circled Key at a range of about 2000 yards. Angler was snorkeling while Key, situated at periscope depth, maintained a 3-knot straight course. Sea states 2 and 3 existed. The water depth was approximately 1650 fathoms. The velocity of sound was estimated at 4975 feet per second.

Figures 22 through 24 illustrate the correlation patterns obtained by hard-limiting, sampling, and beamforming the hydrophone outputs. The ordinate values on each of the plots correspond to a digital number proportional to the beamformer output.

Figure 22 illustrates plots of all 62 of the BQR-7 DIMUS beams. The velocity of sound used to compute the delays for beamforming this data is 5120 feet per second, which is 145 feet per second higher than estimated actual velocity. The steering angles used to beamform the data were chosen on the basis of giving the best coverage for the Key hull configuration.

Figures 23 and 24 are plots of the outputs of four of the aft beams (Beams 2 through 5) and four forward beams (Beams 28 through 31) using a sound velocity of 4950 feet per second. Performance of only those beams most sensitive to the velocity of sound were verified. This was primarily done to conserve computer time since the beamforming runs are quite lengthy.

If the theoretical results are to be verified by actual sea test data, then the response curves of Figures 23 and 24 should show better performance than the corresponding curves illustrated in Figure 22. This should be true especially since the target was at close range where the surface duct is the primary propagation mode. Consequently, beam depression or vertical beam broadening should hinder rather than enhance detection of the target. Upon comparing the response curves of the respective beams, it is observed that the best performance is obtained by calculating time delays using a sound velocity of 4950 feet per second.

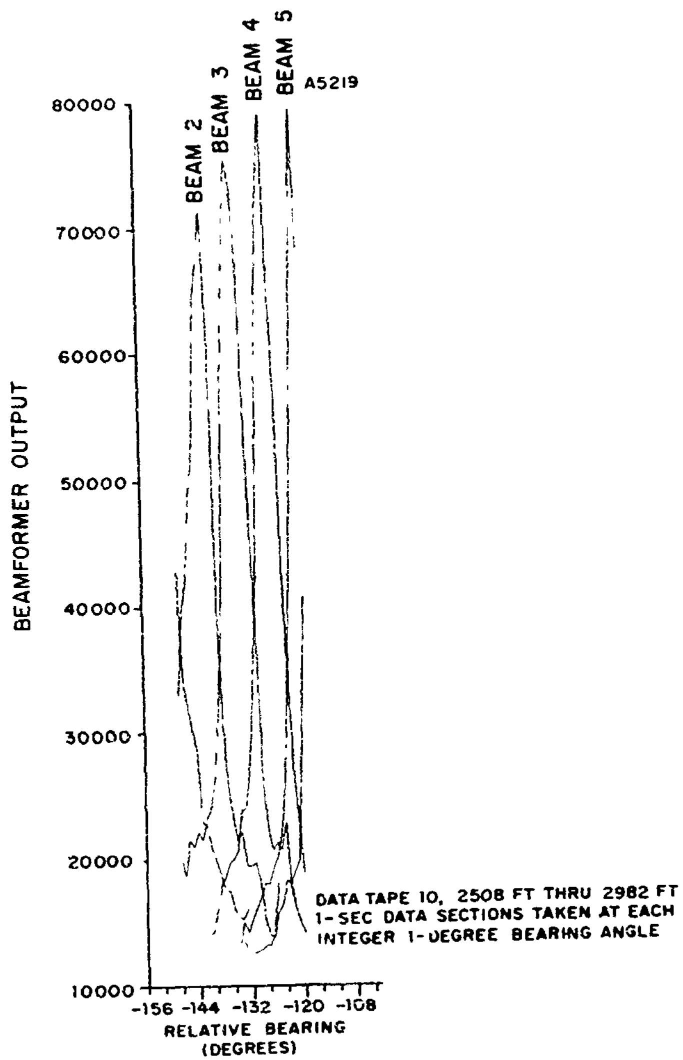

Figure 23. BQR-7 DIMUS Beamformer Correlation Patterns (Beams 2 through 5) Based on a Sound Velcoity of 4950 Feet per Second

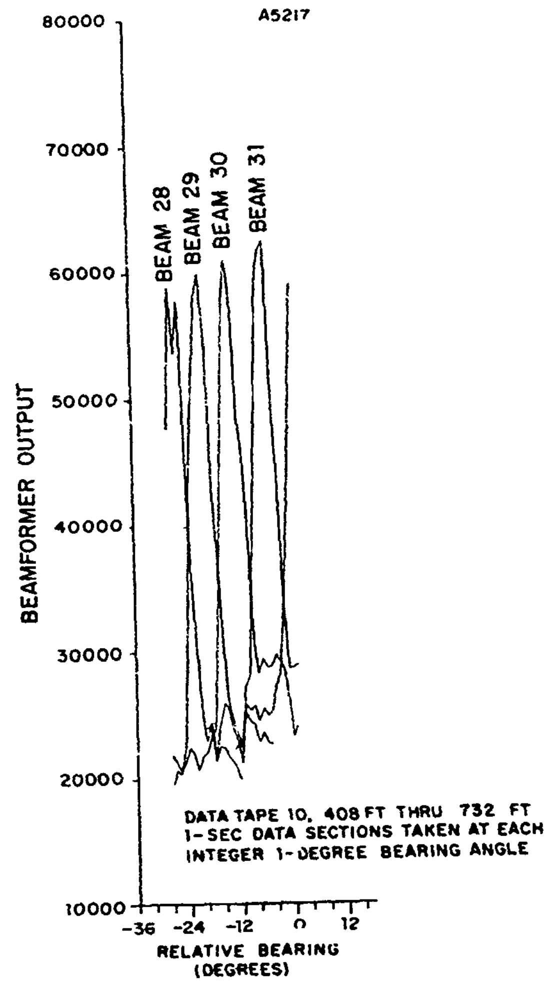

Figure 24. BQR-7 DIMUS Beamformer Correlation Patterns (Beams 28 through 31) Based on a Sound Velocity of 4950 Feet per Second

2. COMPROMISE BEAMFORMER FEASIBILITY STUDY

It was the intent of this phase of the study to determine whether a suitable compromise beamformer, or perhaps two compromise beamformers, could be designed to accommodate the following four classes of submarines.

SS(N) 594*

SS(N) 671

SSB(N) 598

SSB(N) 608**

The definition of a compromise beamformer, as implied here, is that it must provide suitable fixed steering delays to perform the beamforming function for more than one class of submarines. The selection of the time delays for the compromise beamformer must therefore be made on the basis of optimizing the combined performance of more than one class of submarines.

To provide a standard of comparison, the theoretical horizontal beam patterns were calculated for each of the four classes of submarines. These are the patterns which are obtained by computing the steering delays for each class of submarines assuming a sound velocity of 4950 feet per second. These delays are then quantized to the nearest 62-μs interval. The pattern is subsequently generated using these delays in conjunction with Equation (10). For the purpose of generating the theoretical patterns, a flat spectrum having a bandwidth of 1000 Hz and centered at 1000 Hz was assumed. This results in a normalized autocorrelation function as depicted in Figure 25.

The theoretical beam patterns are plotted in Figures 26 through 29. Only 31 of the 62 beams are plotted since the other 31 beams are identical to those shown (because of the symmetry of the array). Note that in each of the theoretical patterns three of the beams are appreciably degraded. This results from the fact that some of the steering delays for these beams are larger than the available delays of the beamformer. Consequently, the output from these elements is added with a delay which is less than required. The delays however, are selected so that there will be positive correlation with the output of the remaining elements. This is achieved by selecting a proper time delay based on the

* The results for the SS(N) 594 are also applicable to the SS(N) 637.

** The results for the SSB(N) 608 are also applicable to the SSB(N) 616 and the SSB(N) 640.

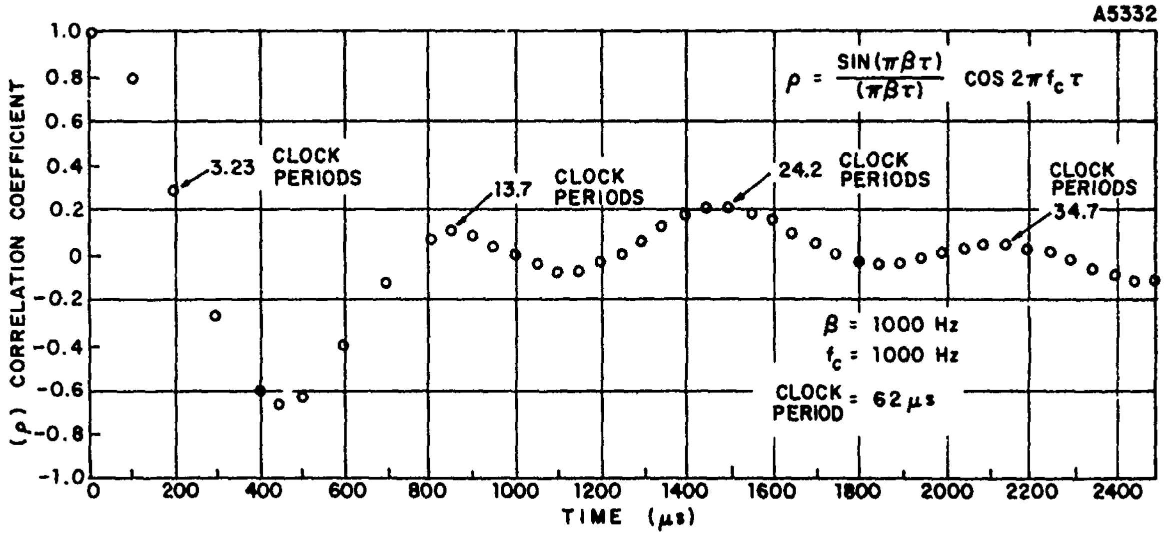

Figure 25. Normalized Autocorrelation Function for Assumed Signal Spectrum

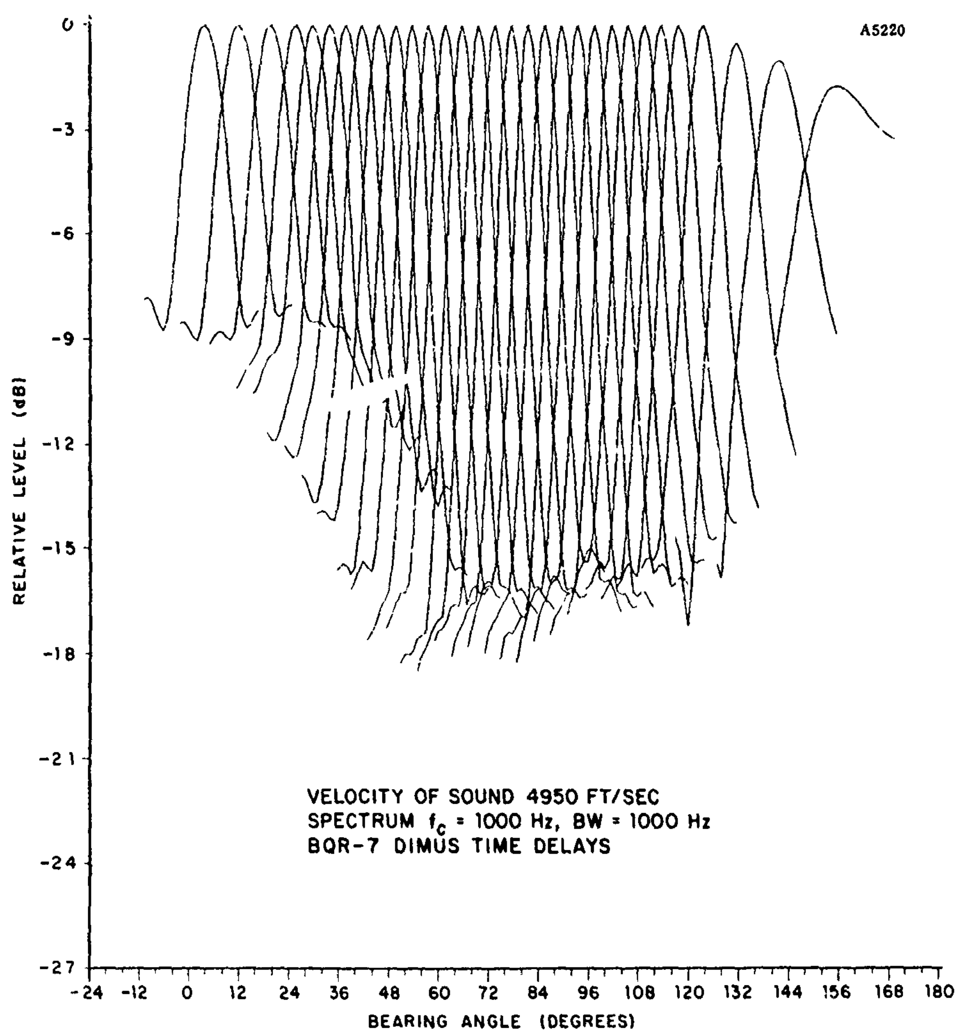

Figure 26. Theoretical Horizontal Beam Patterns for SS(N) 594

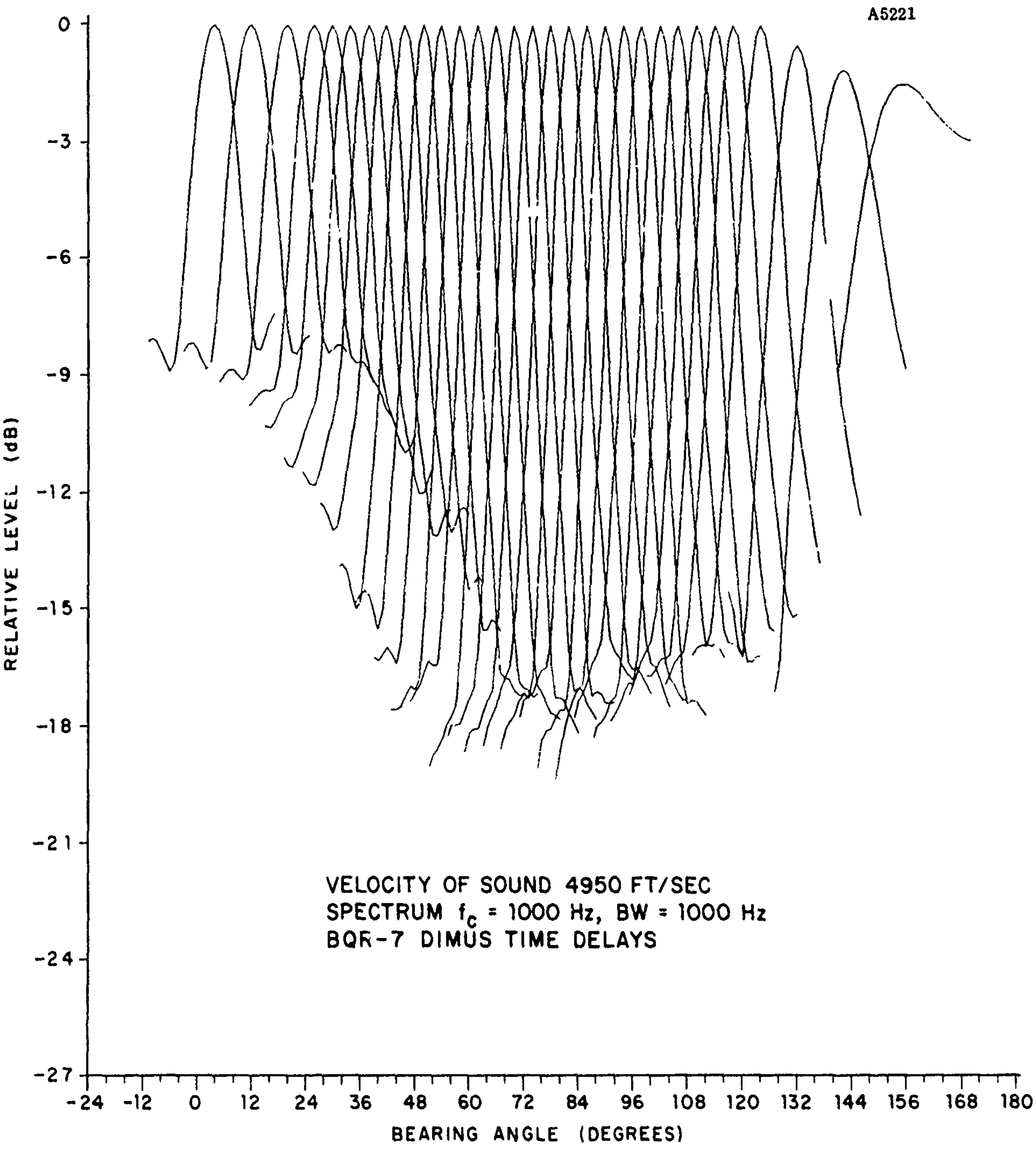

Figure 27. Theoretical Horizontal Beam Patterns for SSB(N) 598

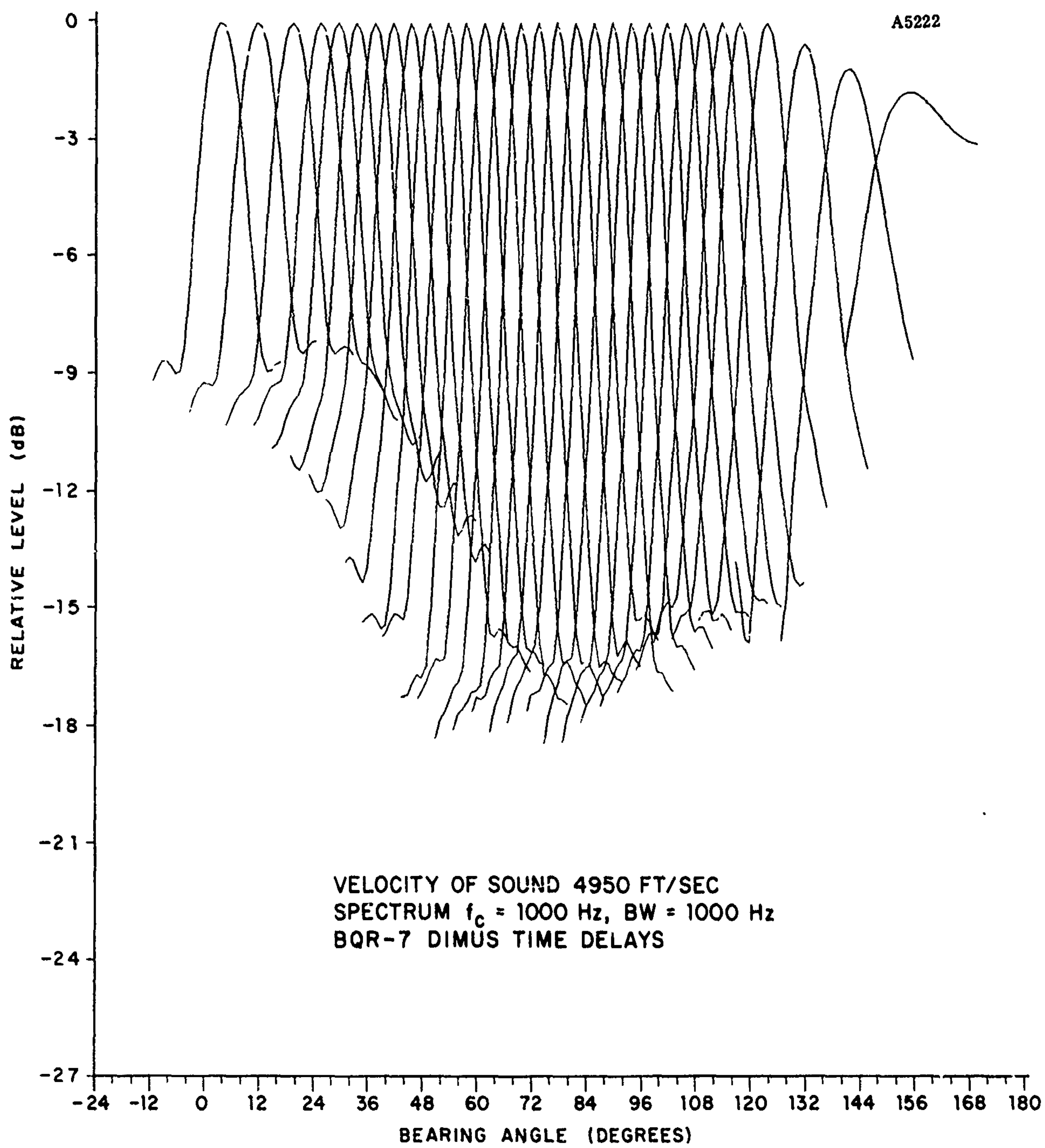

Figure 28. Theoretical Horizontal Beam Patterns for SSB(N) 608

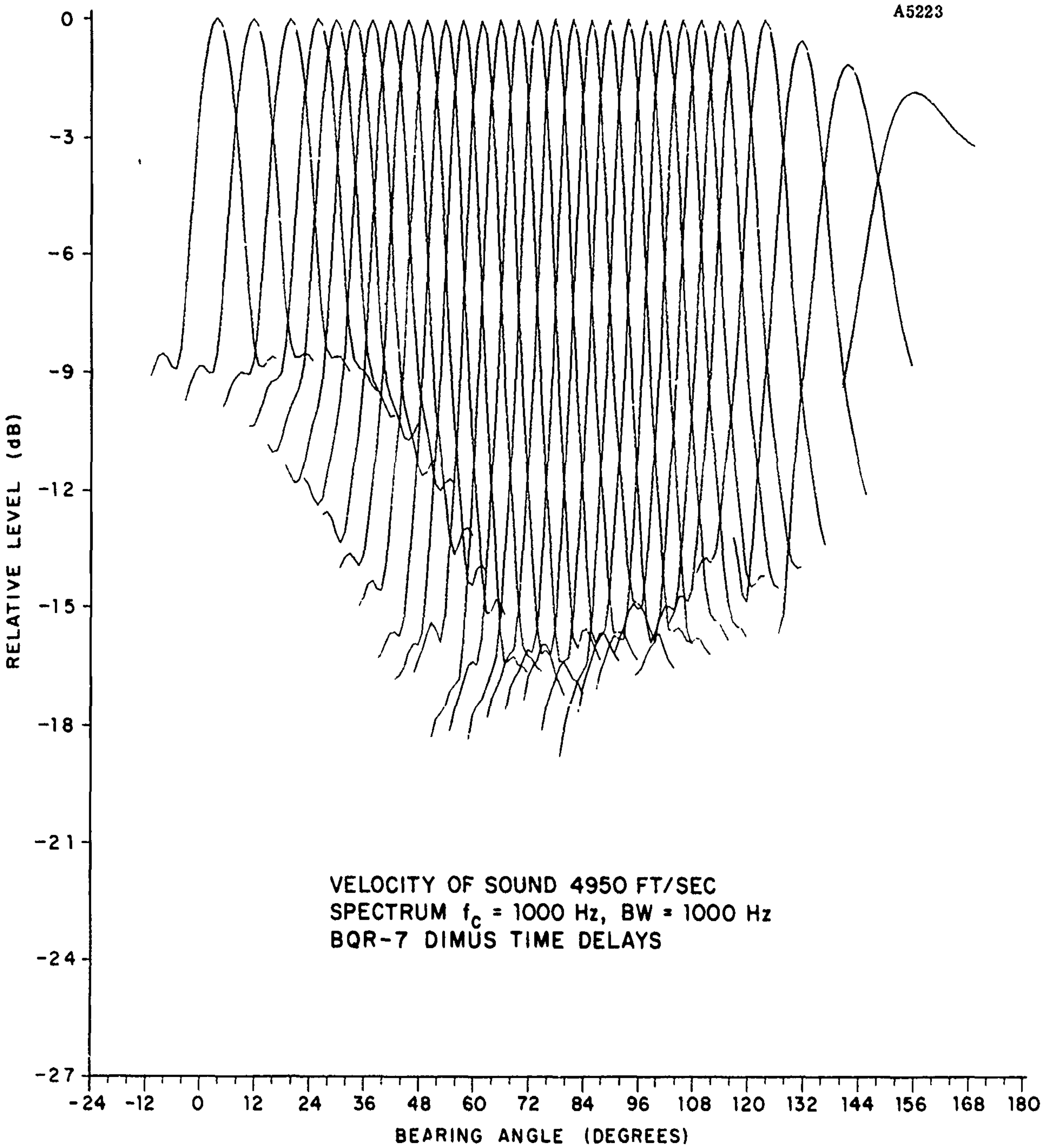

Figure 29. Theoretical Horizontal Beam Patterns for SS(N) 671

normalized autocorrelation function. In practice the elements which are improperly delayed degrade the beam output very little since the elements which are affected have very little response in the boresight direction of the beams involved. The peak responses for the theoretical beam patterns for the four classes of submarines are tabulated in Table 1.

TABLE 1

PEAK RESPONSE OF THEORETICAL BEAM PATTERNS

	Gain (dB)			
Beam Number	SS(N) 594	SSB(N) 598	SSB(N) 608	SS(N) 671
1	-1.69	-1.51	-1.69	-1.78
2	-1.04	-1.04	-1.05	-1.17
3	-0.56	-0.56	-0.56	-0.56
4	-0.03	-0.05	-0.12	-0.15
5	-0.04	-0.04	-0.04	-0.04
6	-0.04	-0.04	-0.04	-0.05
7	-0.03	-0.04	-0.04	-0.04
8	-0.04	-0.04	-0.04	-0.04
9	-0.04	-0.04	-0.04	-0.05
10	-0.04	-0.04	-0.04	-0.03
11	-0.04	-0.04	-0.03	-0.04
12	-0.04	-0.04	-0.03	-0.04
13	-0.04	-0.04	-0.04	-0.04
14	-0.04	-0.03	-0.04	-0.03
15	-0.04	-0.03	-0.03	-0.03
16	-0.04	-0.04	-0.04	-0.04
17	-0.05	-0.04	-0.04	-0.03
18	-0.03	-0.04	-0.04	-0.03
19	-0.04	-0.05	-0.04	-0.05
20	-0.04	-0.04	-0.03	-0.04
21	-0.03	-0.04	-0.04	-0.04
22	-0.04	-0.03	-0.04	-0.04
23	-0.04	-0.04	-0.04	-0.04
24	-0.04	-0.04	-0.04	-0.05
25	-0.05	-0.04	-0.04	-0.04
26	-0.04	-0.04	-0.04	-0.04
27	-0.04	-0.05	-0.03	-0.04
28	-0.04	-0.04	-0.04	-0.03
29	-0.05	-0.04	-0.04	-0.05
30	-0.04	-0.04	-0.04	-0.04
31	-0.04	-0.04	-0.03	-0.04

Compromise beamformers were investigated for various combinations of array configurations (classes of submarines). The delay values for the compromise beamformer were calculated on the basis of the following method. The average delay value per element was computed for each beam and class of submarine. The average delay value was then adjusted so that the corresponding beam of each class of submarine possessed the same average delay per element. The adjustment was made by adding or subtracting a constant to each delay value for each beam (different for each beam but the same for each element). This does not alter the pattern since it is only the delay difference between elements which is instrumental in producing the pattern. Thereafter, the mean value of the delays of the corresponding elements in corresponding beams was computed to determine the compromise delay values. Any constant delay which had been added or subtracted to adjust the mean delay per element was then reinstated.

Figures 30 through 33 illustrate the beam patterns for the four classes of submarines if a single compromise beamformer was designed to handle all four classes. Table 2 lists the corresponding peak responses for each class submarine using the four-array compromise and plots of these losses are shown in Figure 34.

Figures 35 through 37 are the beam patterns for the SS(N) 594, SSB(N) 598, and the SSB(N) 608 using a compromise beamformer for these three classes of submarines.

The corresponding losses in peak response are tabulated in Table 3 and a plot of these losses is shown in Figure 38. Various other two-array compromises were attempted. The corresponding beam patterns are shown in Figures 39 through 51. The resulting losses in peak response are tabulated in Table 4 and plotted in Figures 52 through 54.

The "worst case" losses in peak response resulting from all combinations of compromise delay values were tabulated on a beam to beam basis. These are plotted in Figure 55.

The arrival times and the sampling times for numerous configurations have been compiled and are shown in Figures 56 through 63. The arrival time is computed by subtracting the delay time from a positive constant greater than the largest required delay. The relationship between the delay times and the sampling times, however, is not so obvious. Using the beamformer design as given in "Final Report, AN/BQR-7, All Digital Preformed Beam Receiver Study (U)" dated September 30, 1965, the sampling times can be computed from the arrival time as outlined in this document.

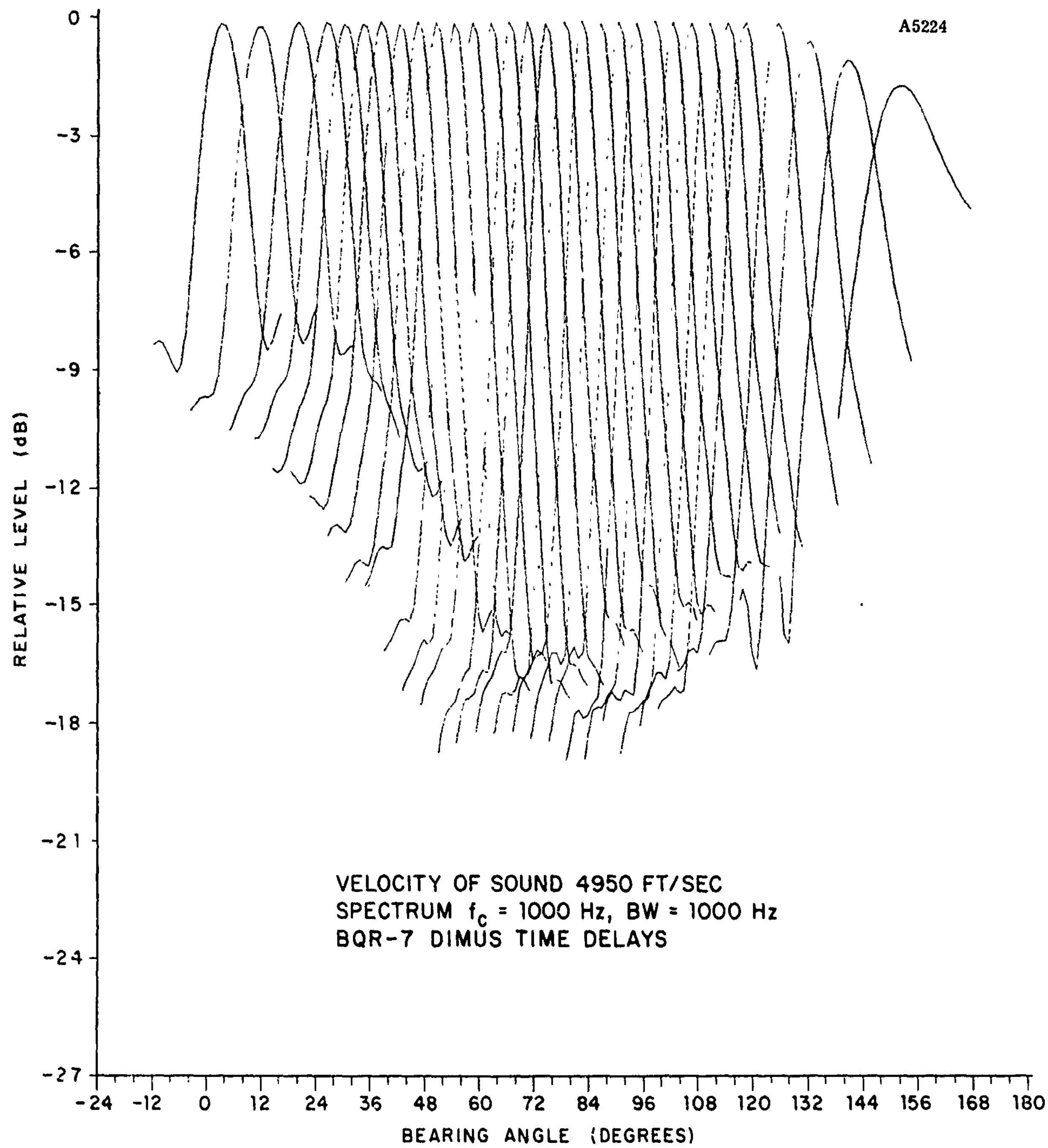

Figure 30. Horizontal Beam Patterns of SS(N) 594 Using a Four-Array Compromise Beamformer Based on SS(N) 594, SSB(N) 598, SSB(N) 608, and SS(N) 671 Configurations

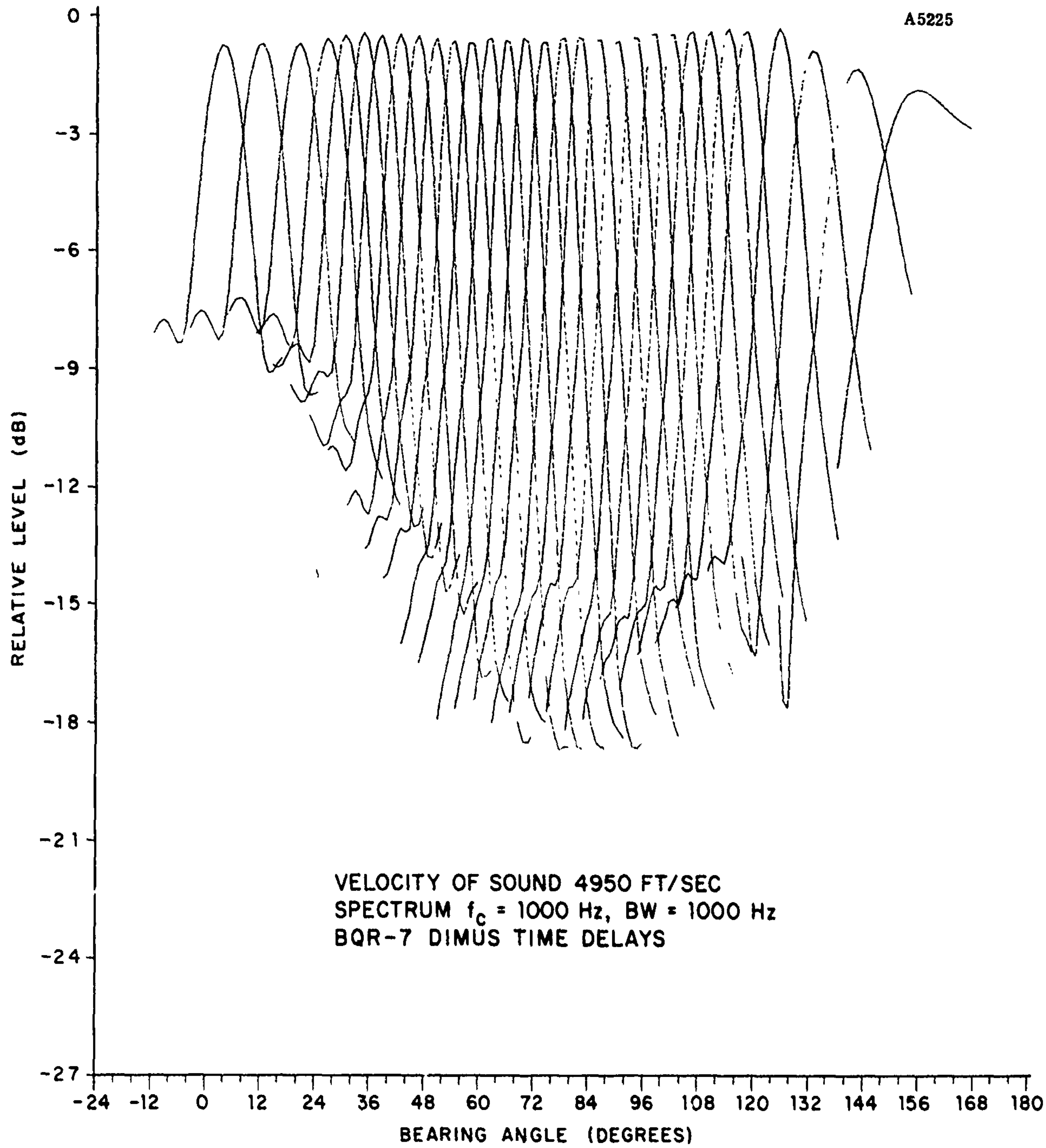

Figure 31. Horizontal Beam Patterns of SSB(N) 598 Using a Four-Array Compromise Beamformer Based on SS(N) 594, SSB(N) 598, SSB(N) 608, and SS(N) 671 Configurations

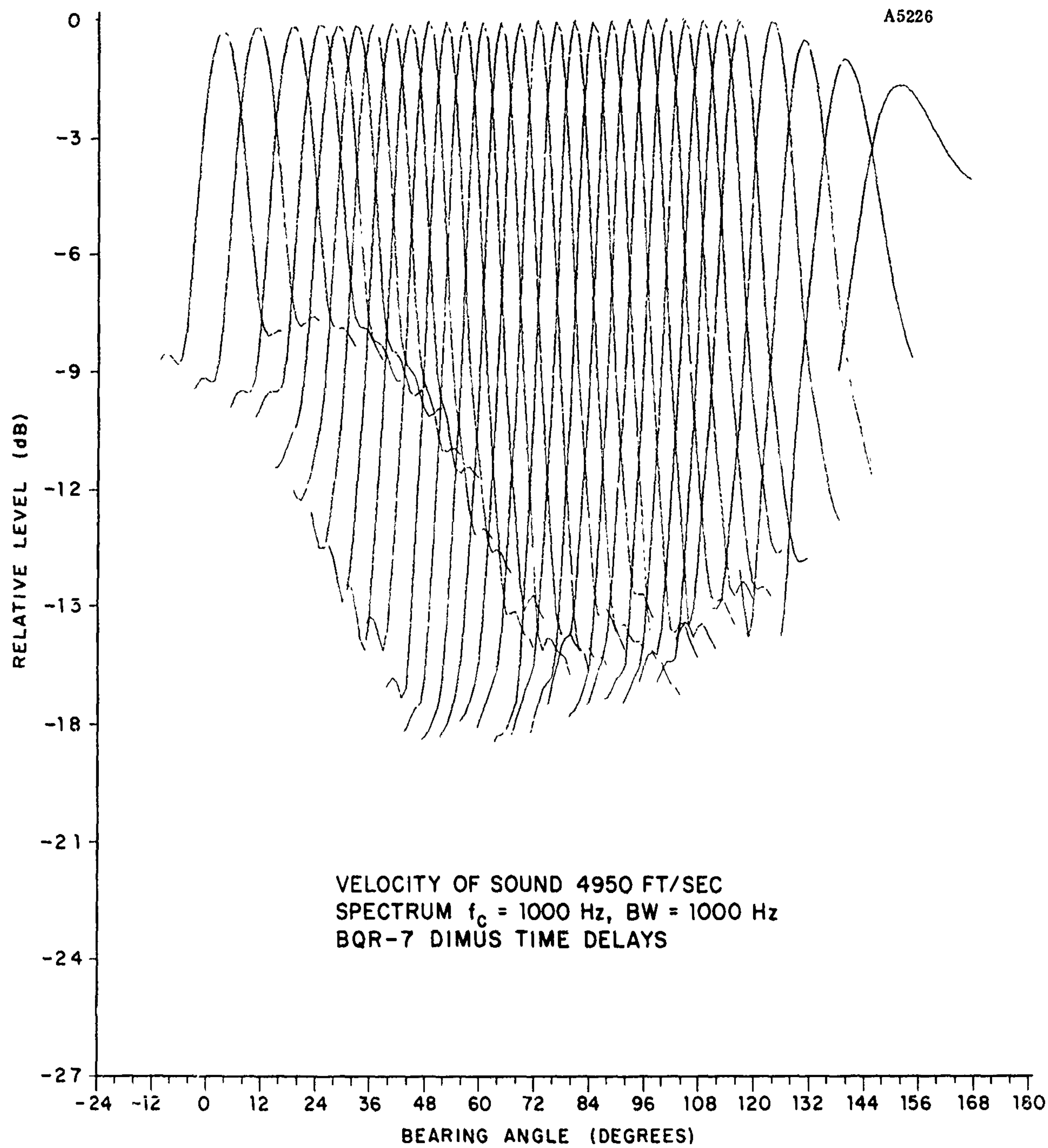

Figure 32. Horizontal Beam Patterns of SSB(N) 608 Using a Four-Array Compromise Beamformer Based on SS(N) 594, SSB(N) 598, SSB(N) 608, and SS(N) 671 Configurations

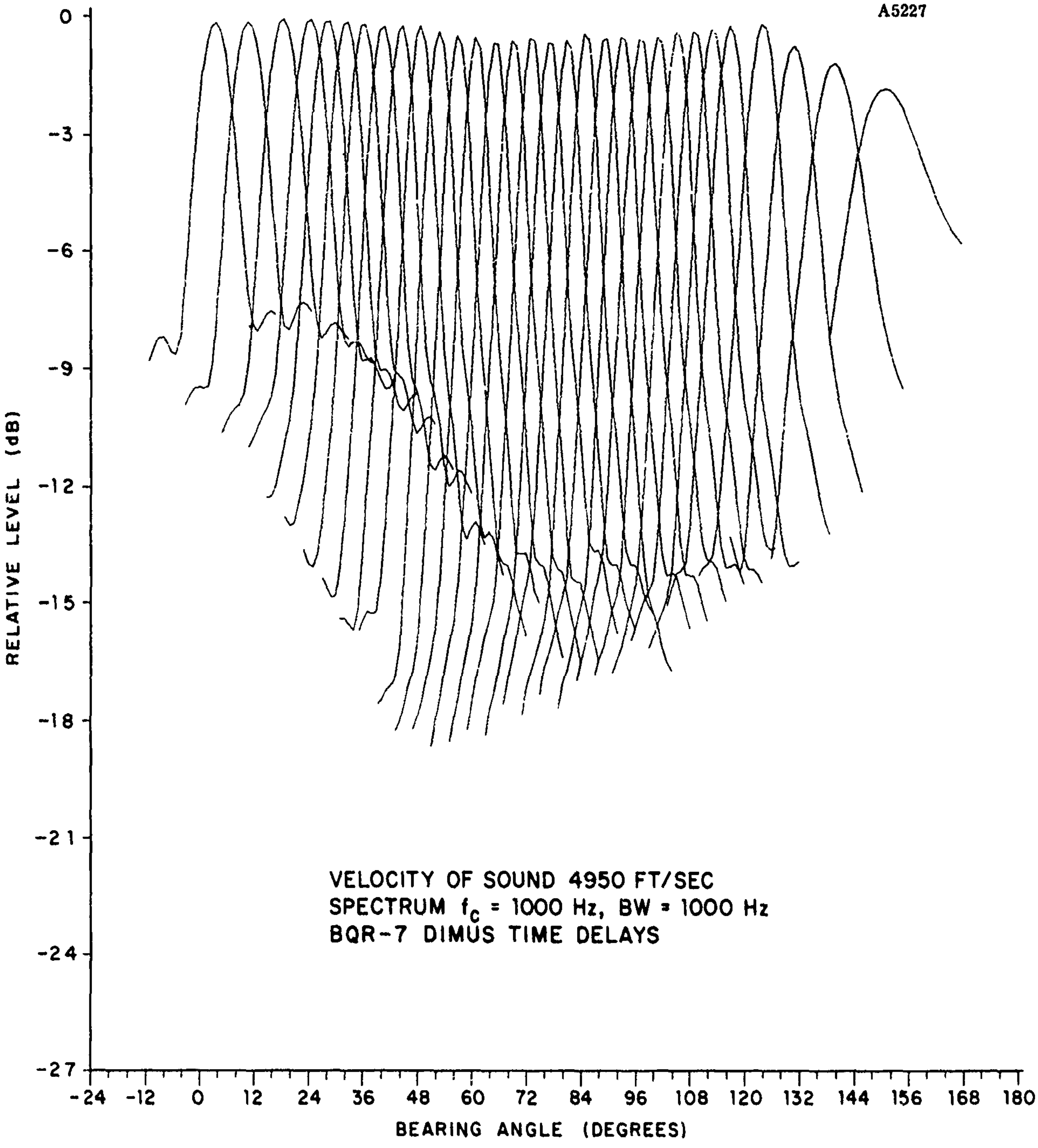

Figure 33. Horizontal Beam Patterns of SS(N) 671 Using a Four-Array Compromise Beamformer Based on SS(N) 594, SSB(N) 598, SSB(N) 608, and SS(N) 671 Configurations

TABLE 2

PEAK RESPONSE VALUES FOR FOUR-ARRAY COMPROMISE

Beam Number	Gain (dB) SS(N) 594	Gain (dB) SSB(N) 598	Gain (dB) SSB(N) 608	Gain (dB) SS(N) 671
1	-1.73	-1.83	-1.71	-1.85
2	-1.09	-1.28	-1.08	-1.22
3	-0.60	-0.82	-0.60	-0.77
4	-0.13	-0.25	-0.14	-0.24
5	-0.15	-0.32	-0.11	-0.28
6	-0.12	-0.27	-0.10	-0.37
7	-0.14	-0.34	-0.08	-0.42
8	-0.11	-0.32	-0.02	-0.46
9	-0.10	-0.41	-0.04	-0.57
10	-0.07	-0.39	-0.07	-0.62
11	-0.12	-0.50	-0.06	-0.57
12	-0.07	-0.58	-0.08	-0.58
13	-0.12	-0.54	-0.12	-0.49
14	-0.06	-0.49	-0.08	-0.64
15	-0.10	-0.51	-0.10	-0.69
16	-0.13	-0.62	-0.08	-0.60
17	-0.08	-0.53	-0.14	-0.66
18	-0.08	-0.59	-0.14	-0.72
19	-0.10	-0.54	-0.13	-0.57
20	-0.11	-0.64	-0.10	-0.52
21	-0.11	-0.57	-0.11	-0.42
22	-0.10	-0.52	-0.09	-0.26
23	-0.09	-0.44	-0.17	-0.28
24	-0.16	-0.40	-0.16	-0.29
25	-0.07	-0.44	-0.16	-0.26
26	-0.14	-0.38	-0.21	-0.19
27	-0.15	-0.45	-0.18	-0.17
28	-0.11	-0.54	-0.20	-0.12
29	-0.09	-0.66	-0.23	-0.12
30	-0.20	-0.67	-0.24	-0.20
31	-0.12	-0.72	-0.31	-0.21

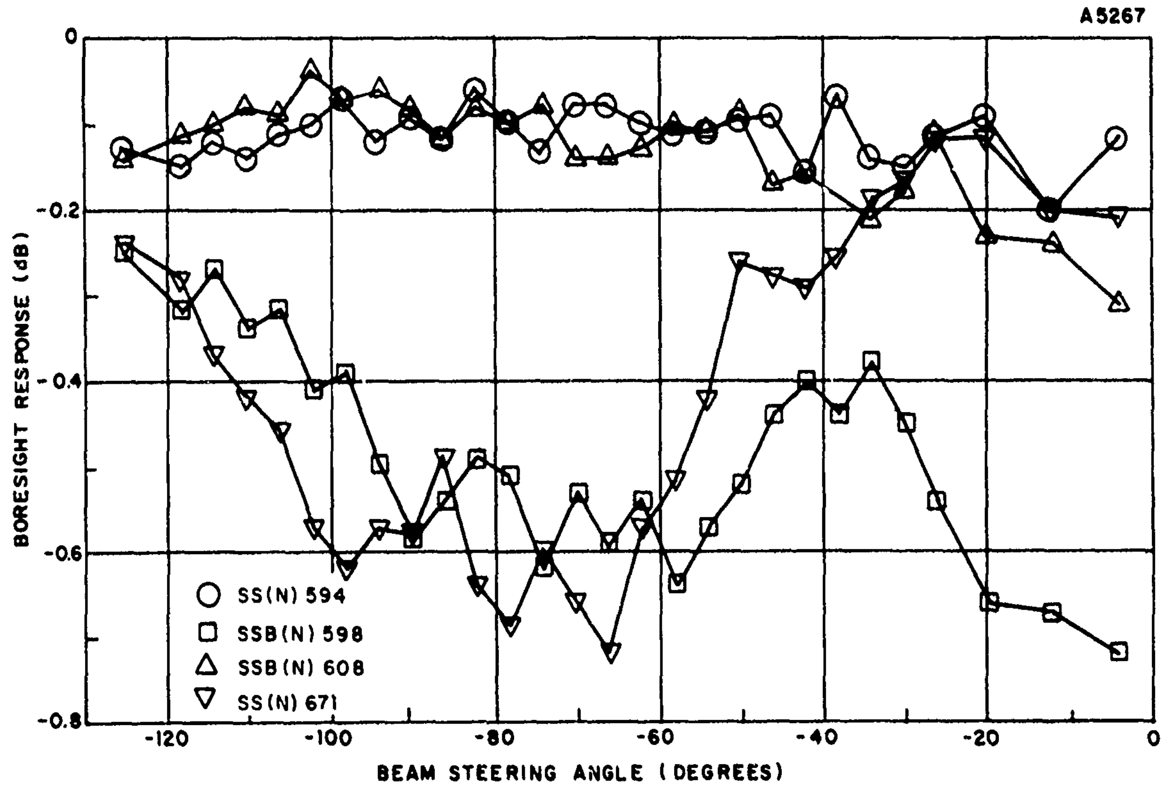

Figure 34. Plot of Peak Response Values for Four-Array Compromise

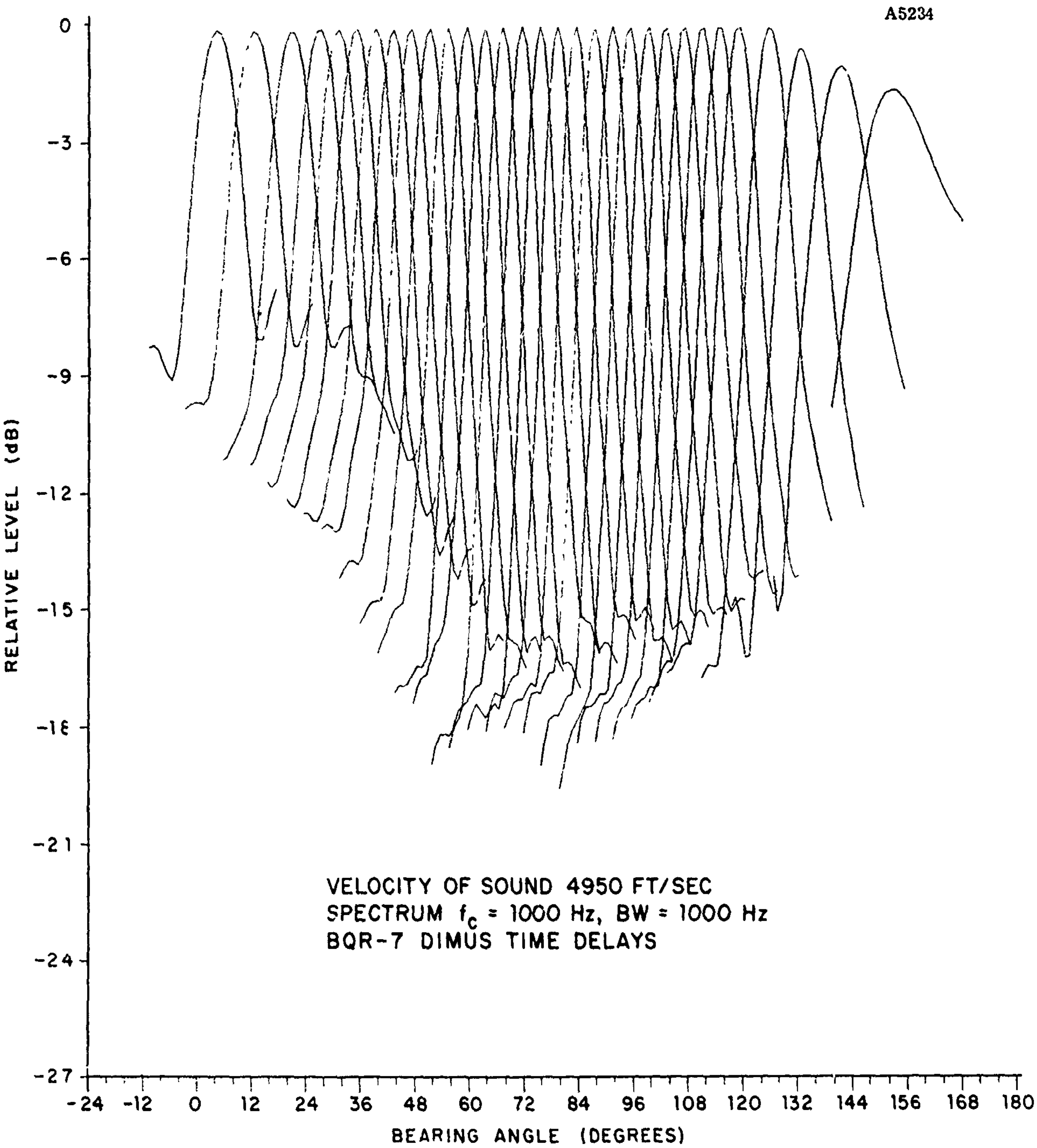

Figure 35. Horizontal Beam Patterns of SS(N) 594 Using a Three-Array Compromise Beamformer Based on SS(N) 594, SSB(N) 598, and SSB(N) 608 Configurations

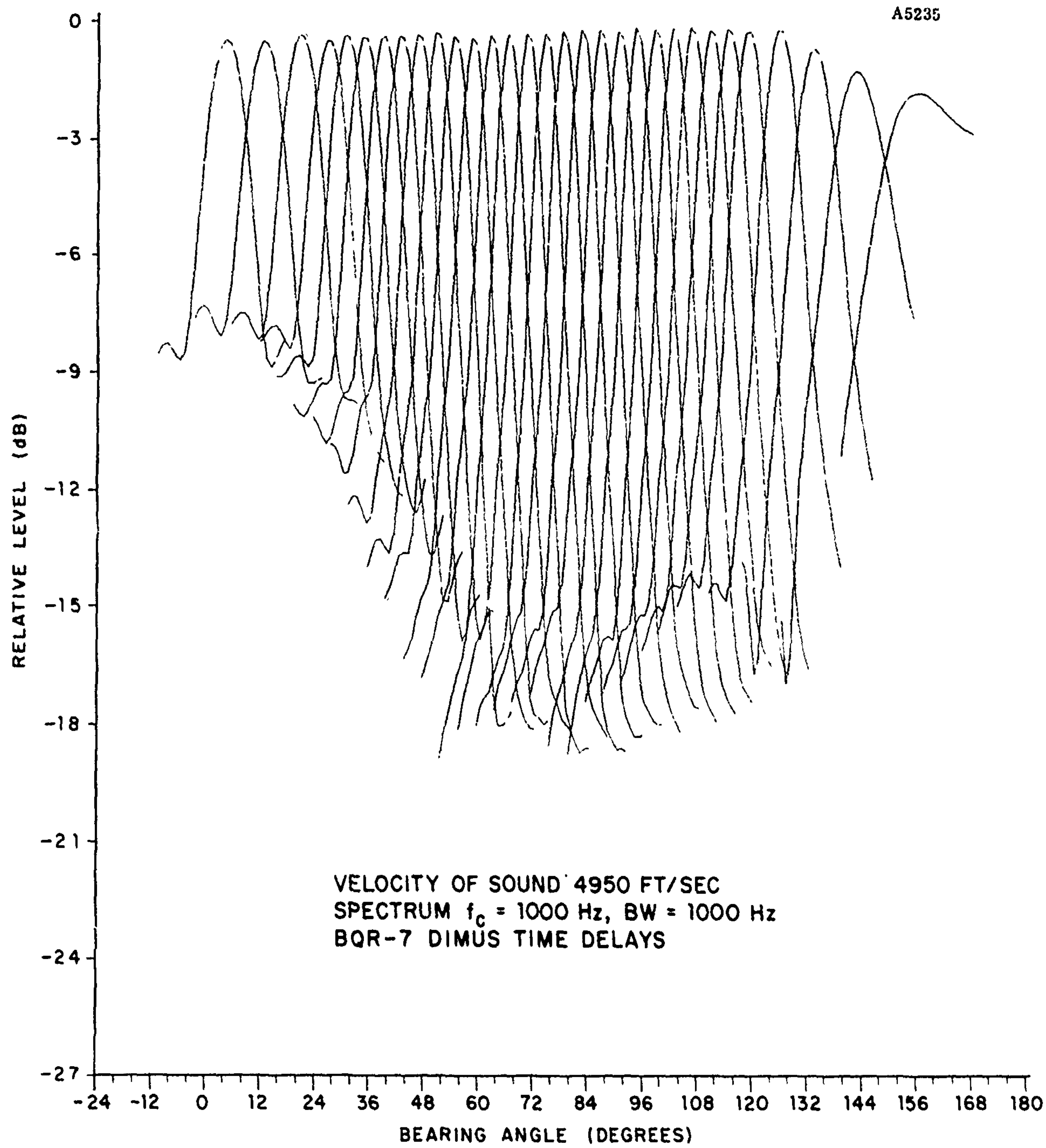

Figure 36. Horizontal Beam Patterns of SSB(N) 598 Using a Three-Array Compromise Beamformer Based on SS(N) 594, SSB(N) 598, and SSB(N) 608 Configurations

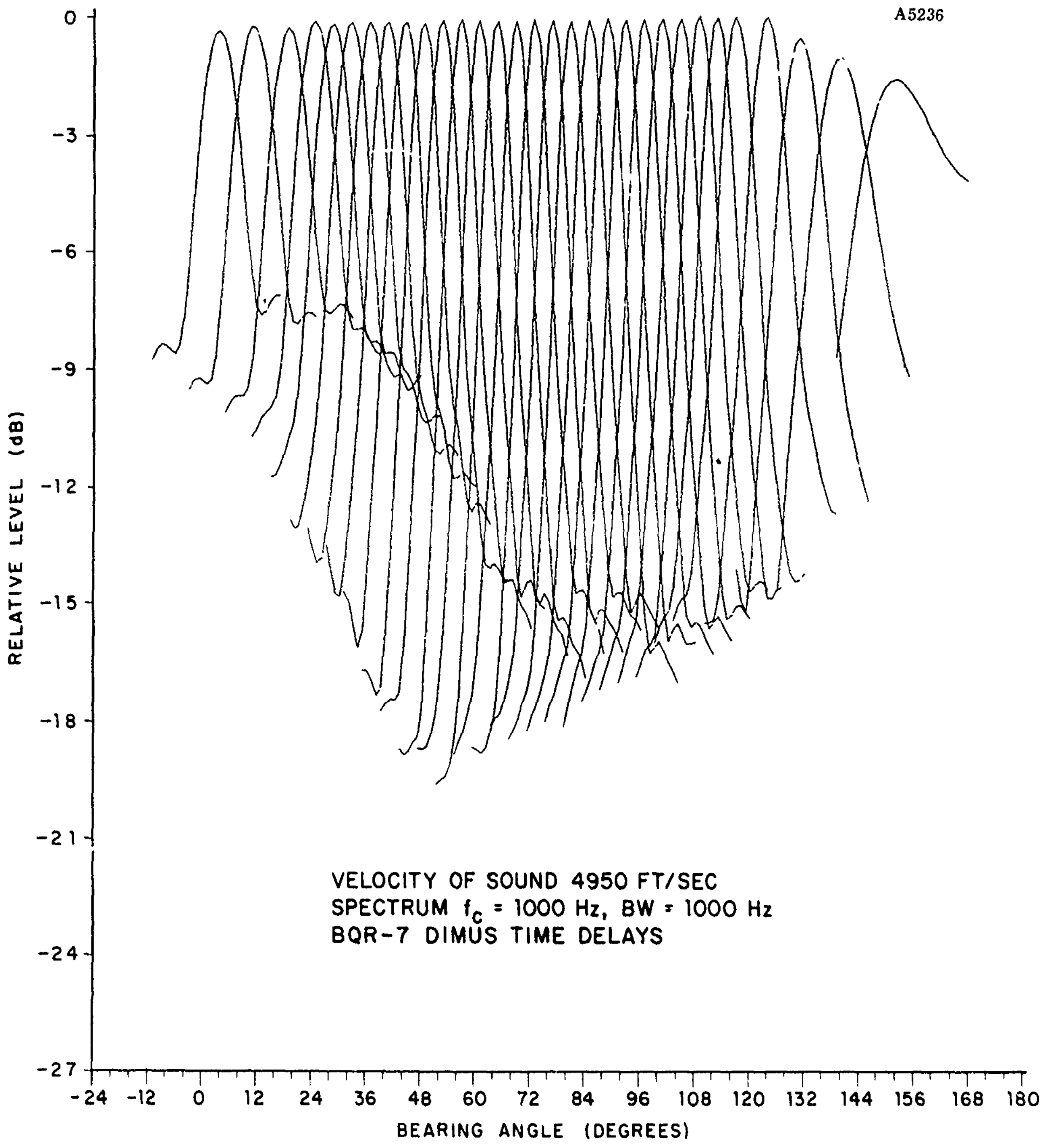

Figure 37. Horizontal Beam Patterns of SSB(N) 608 Using a Three-Array Compromise Beamformer Based on SS(N) 594, SSB(N) 598, and SSB(N) 608 Configurations

TABLE 3

PEAK RESPONSE VALUES FOR THREE-ARRAY COMPROMISE

Beam Number	Gain (dB)		
	SS(N) 594	SSB(N) 598	SSB(N) 608
1	-1.70	-1.82	-1.67
2	-1.09	-1.26	-1.09
3	-0.65	-0.69	-0.62
4	-0.13	-0.22	-0.08
5	-0.10	-0.26	-0.09
6	-0.13	-0.19	-0.10
7	-0.12	-0.23	-0.06
8	-0.13	-0.16	-0.12
9	-0.12	-0.17	-0.12
10	-0.10	-0.20	-0.13
11	-0.13	-0.16	-0.16
12	-0.08	-0.27	-0.10
13	-0.09	-0.22	-0.17
14	-0.09	-0.22	-0.17
15	-0.09	-0.25	-0.16
16	-0.09	-0.30	-0.14
17	-0.09	-0.32	-0.17
18	-0.10	-0.33	-0.19
19	-0.13	-0.36	-0.16
20	-0.10	-0.43	-0.13
21	-0.14	-0.38	-0.15
22	-0.13	-0.31	-0.24
23	-0.15	-0.35	-0.20
24	-0.17	-0.41	-0.19
25	-0.13	-0.38	-0.17
26	-0.16	-0.44	-0.19
27	-0.18	-0.40	-0.24
28	-0.14	-0.52	-0.17
29	-0.24	-0.37	-0.34
30	-0.22	-0.55	-0.30
31	-0.19	-0.51	-0.39

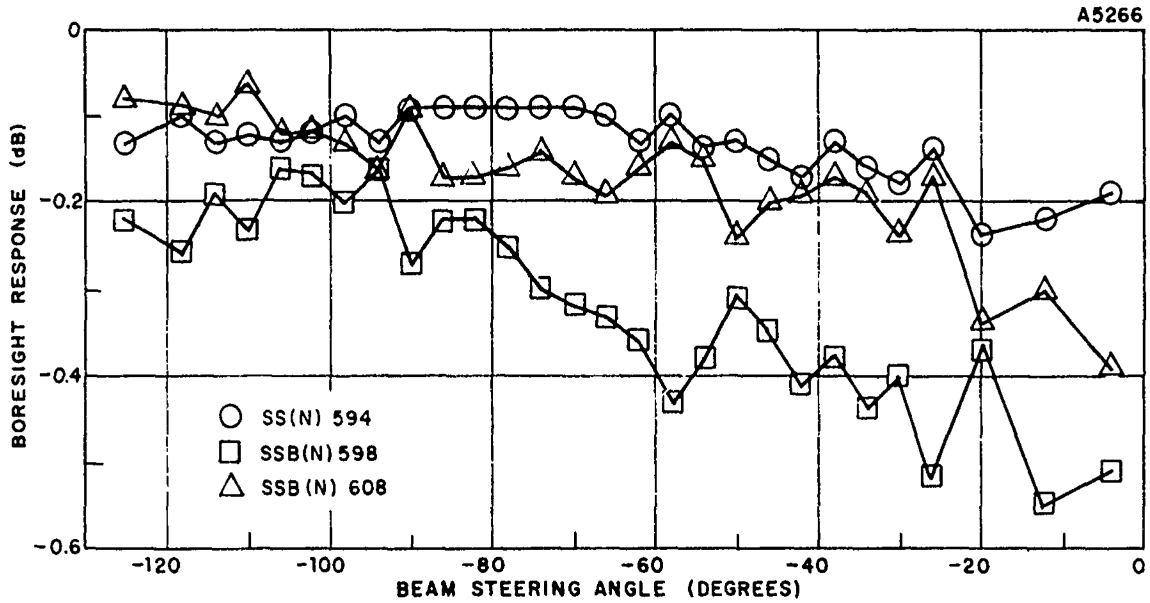

Figure 38. Plot of Peak Response Values for Three-Array Compromise

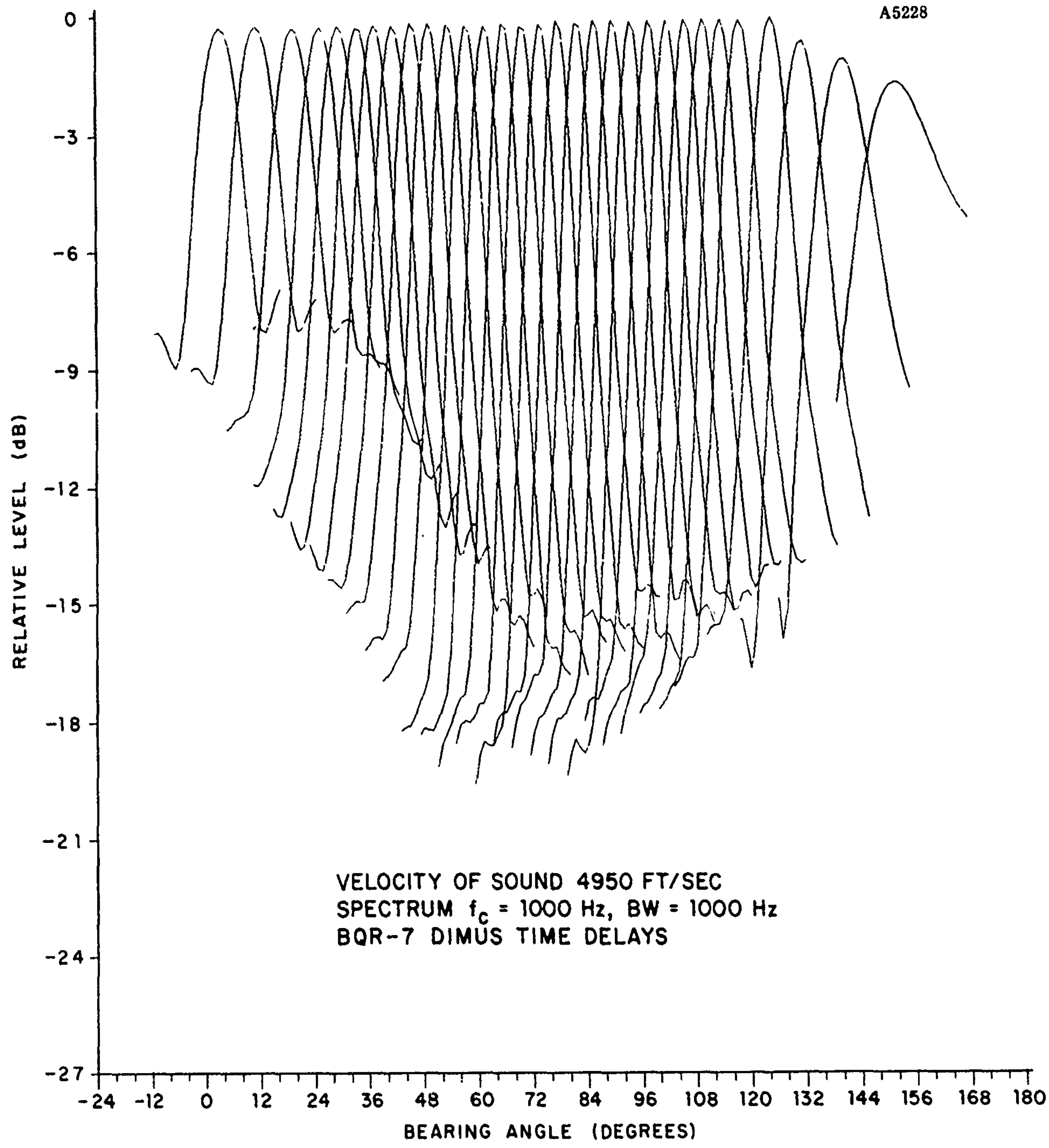

Figure 39. Hor'zontal Beam Patterns of SS(N) 594 Using a Two-Array Compromise Beamformer Based on SS(N) 594 and SSB(N) 598 Configurations

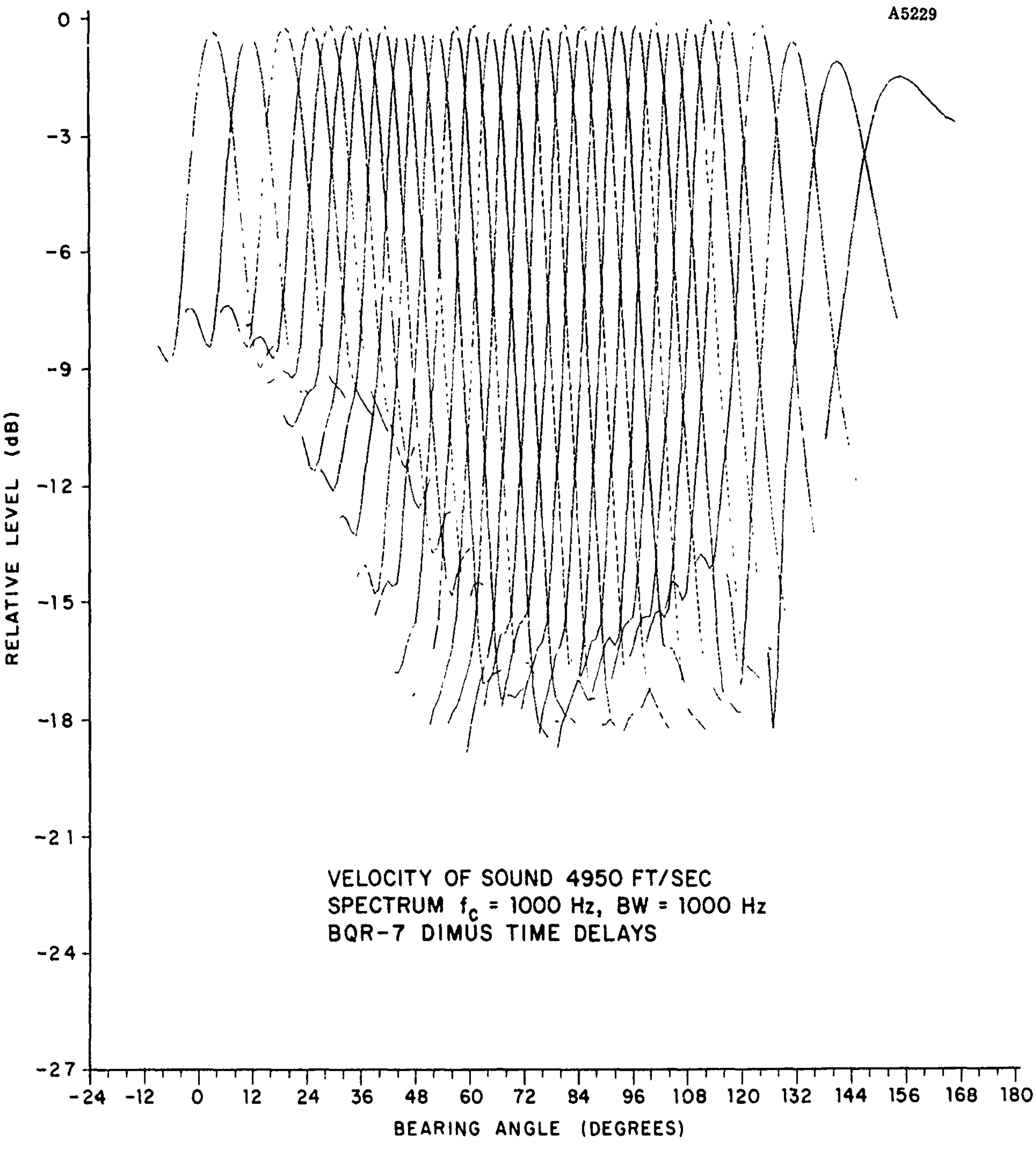

Figure 40. Horizontal Beam Patterns of SSB(N) 598 Using a Two-Array Compromise Beamformer Based on SS(N) 594 and SSB(N) 598 Configurations

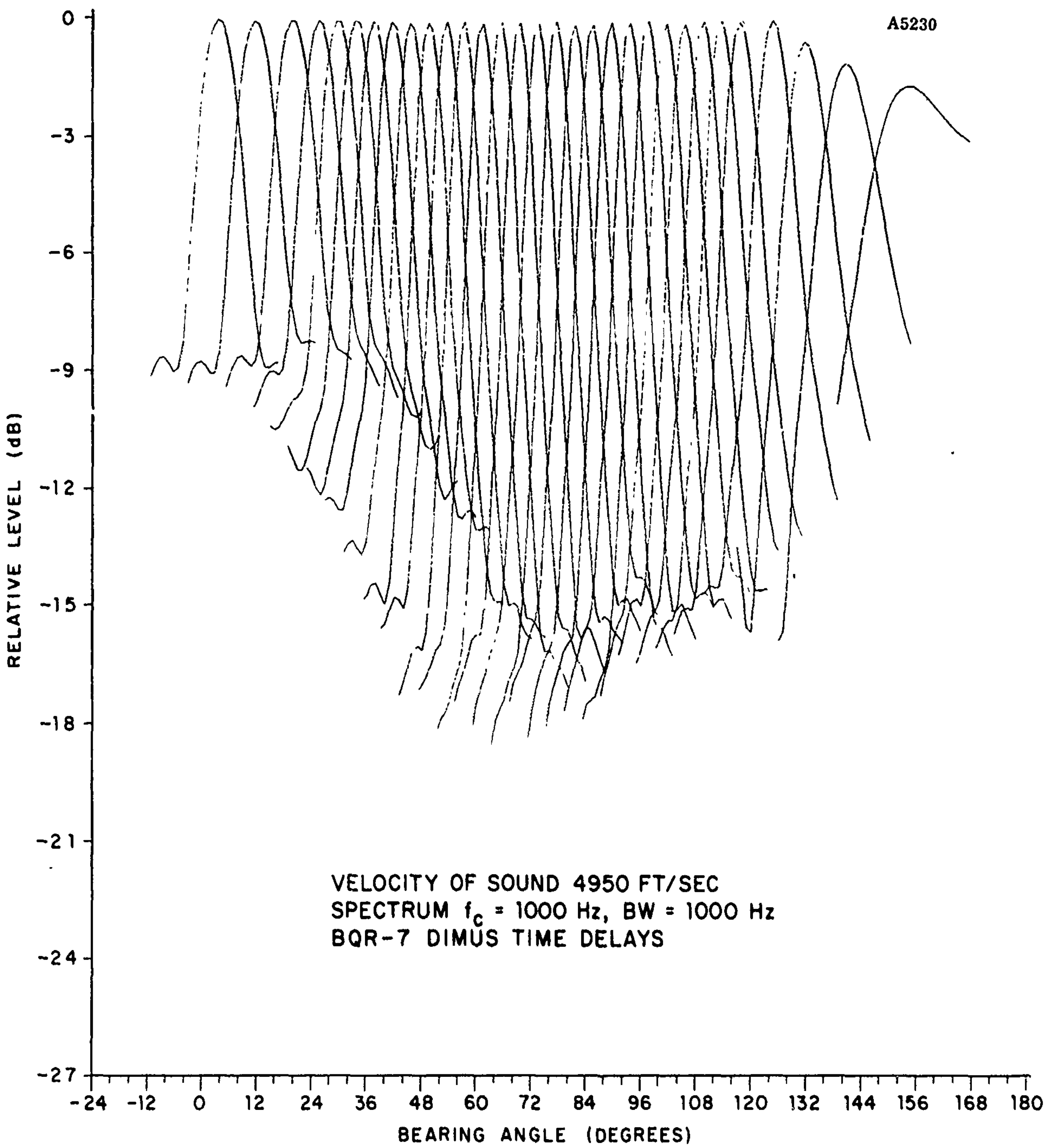

Figure 41. Horizontal Beam Patterns of SSB(N) 608 Using a Two-Array Compromise Beamformer Based on SSB(N) 608 and SS(N) 671 Configurations

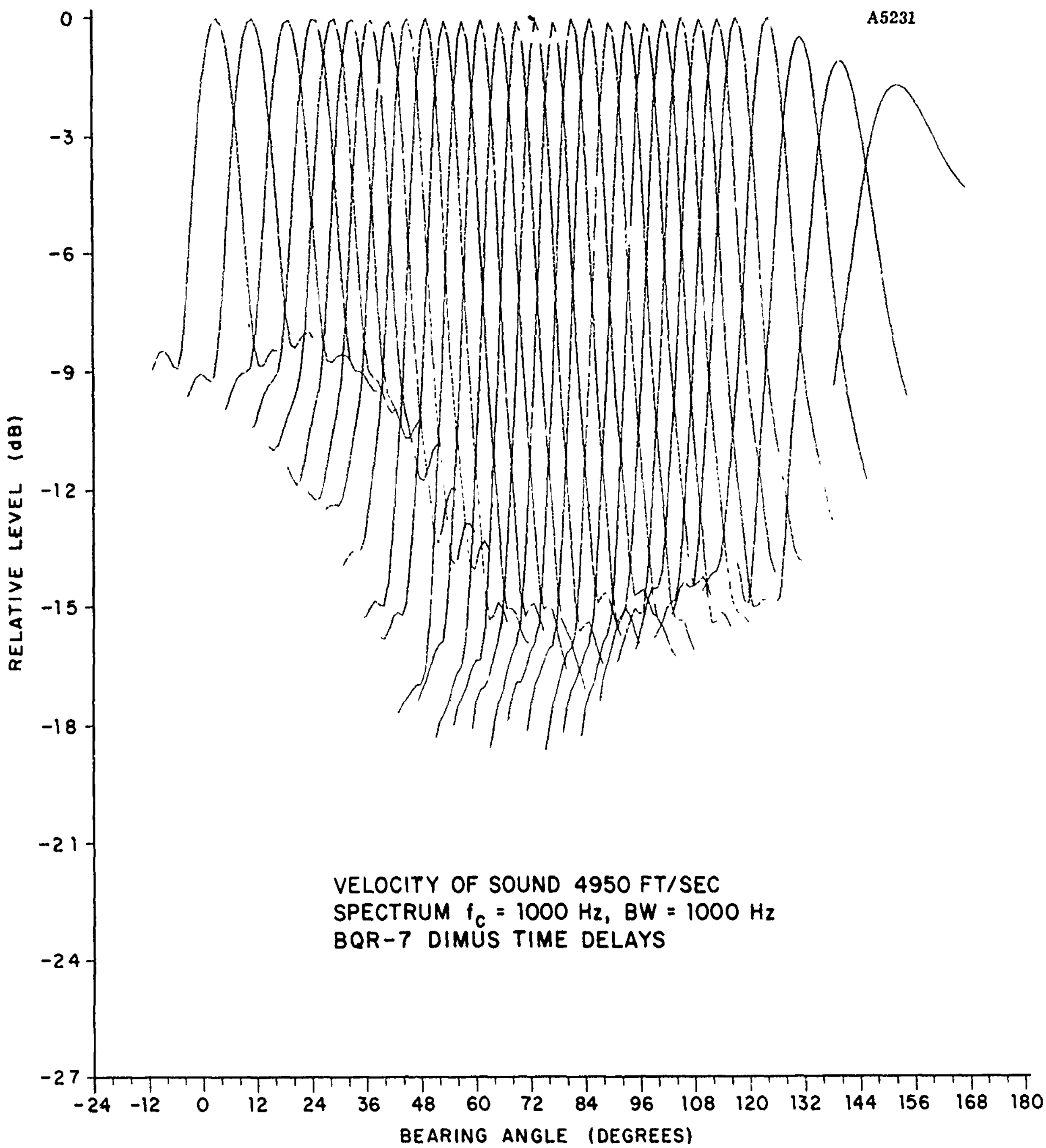

Figure 42. Horizontal Beam Patterns of SS(N) 671 Using a Two-Array Compromise Beamformer Based on SSB(N) 608 and SS(N) 671 Configurations

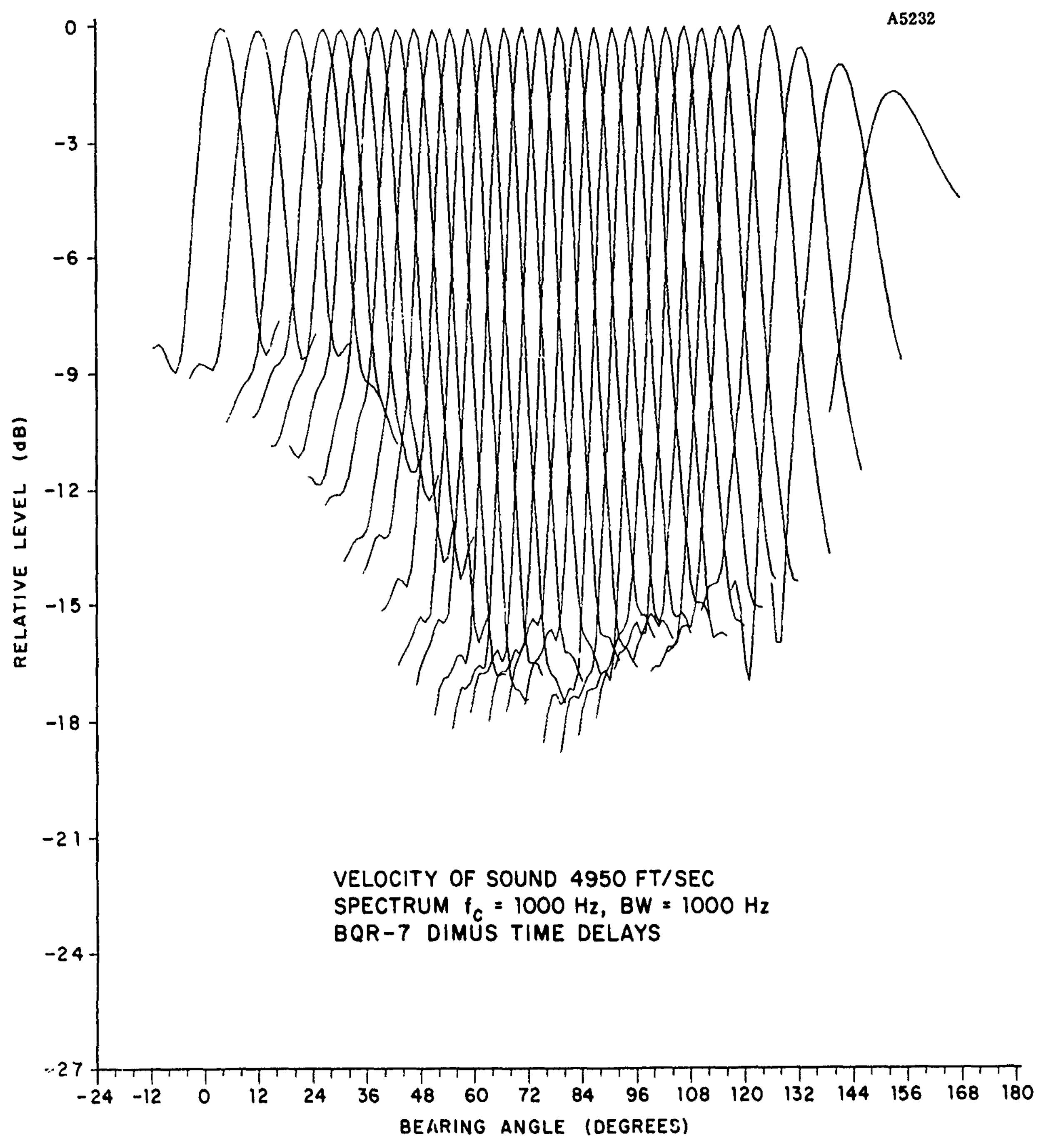

Figure 43. Horizontal Beam Patterns of SS(N) 594 Using a Two-Array Compromise Beamformer Based on SS(N) 594 and SSB(N) 608 Configurations

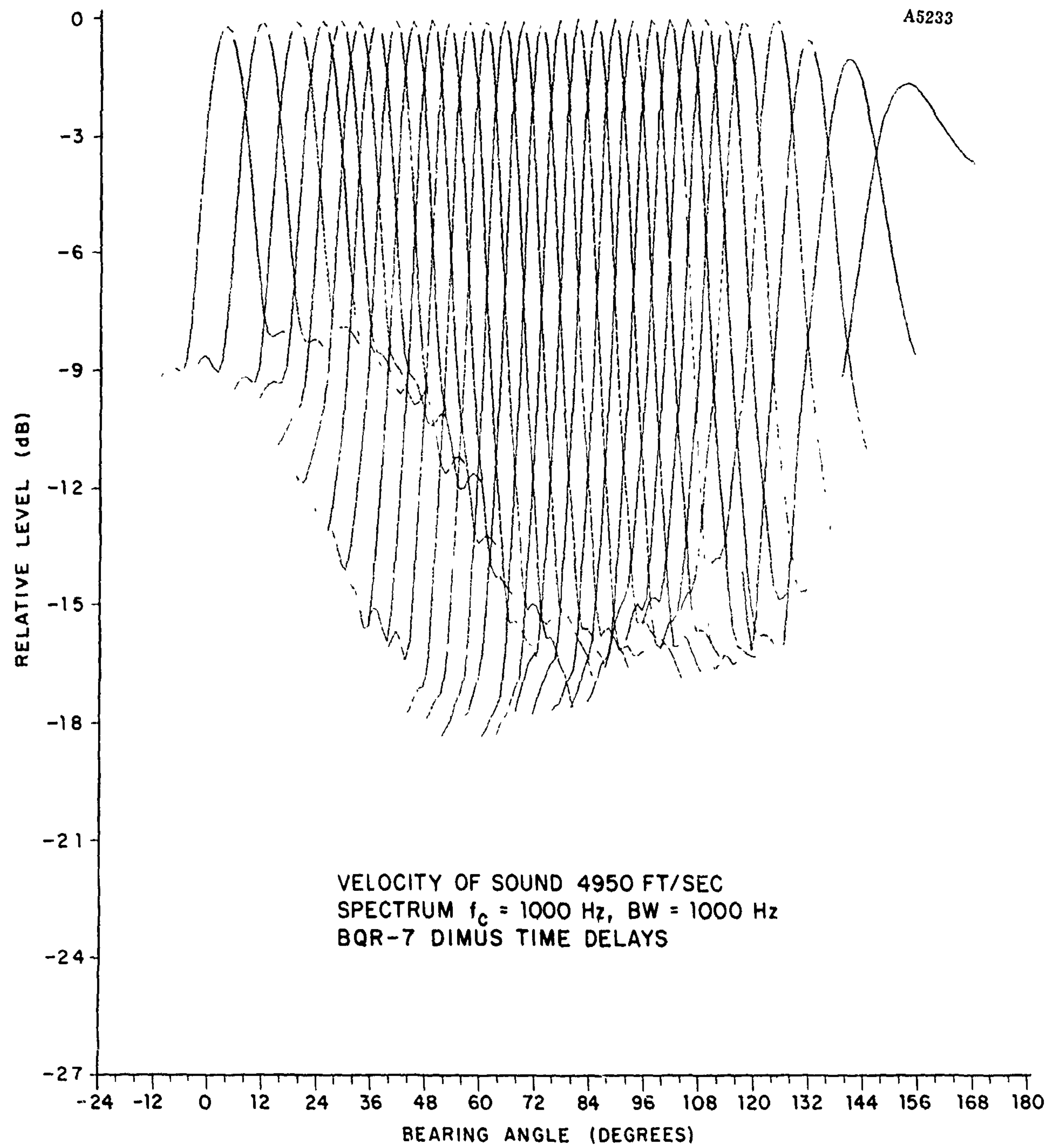

Figure 44. Horizontal Beam Patterns of SSB(N) 608 Using a Two-Array Compromise Beamformer Based on SS(N) 594 and SSB(N) 608 Configurations

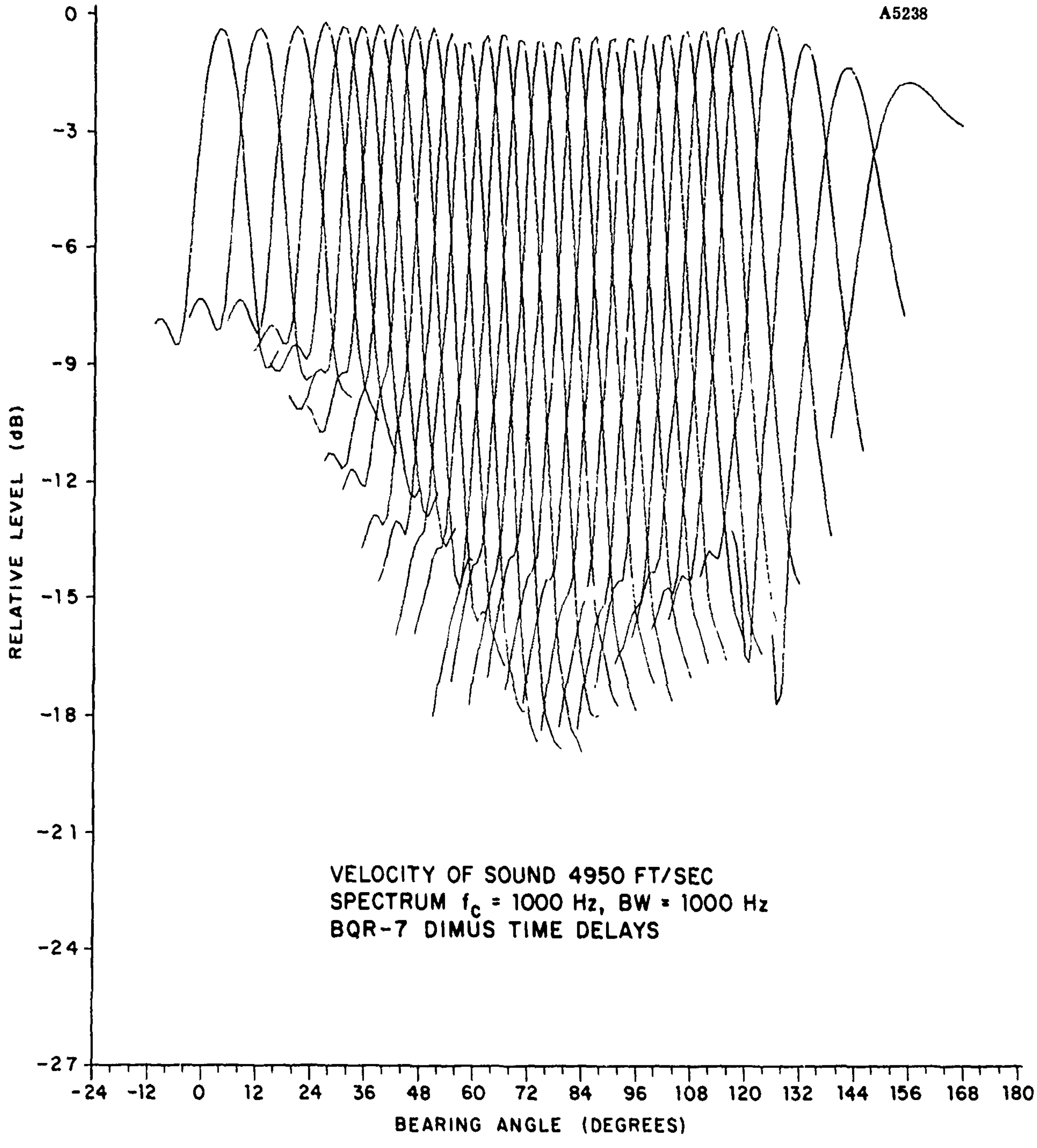

Figure 45. Horizontal Beam Patterns of SSB(N) 598 Using a Two-Array Compromise Beamformer Based on SSB(N) 598 and SS(N) 671 Configurations

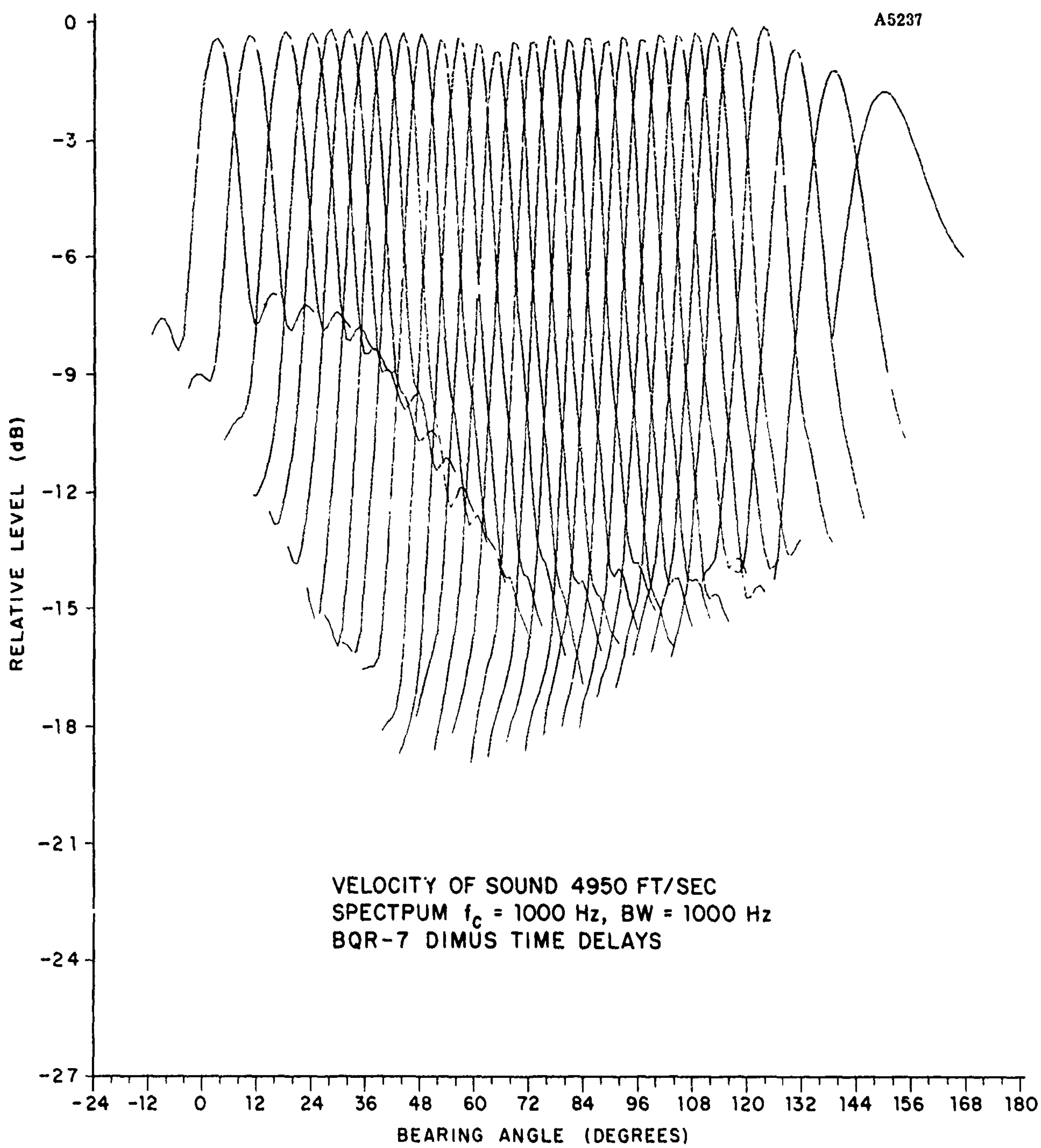

Figure 46. Horizontal Beam Patterns of SS(N) 671 Using a Two-Array Compromise Beamformer Based on SSB(N) 598 and SS(N) 671 Configurations

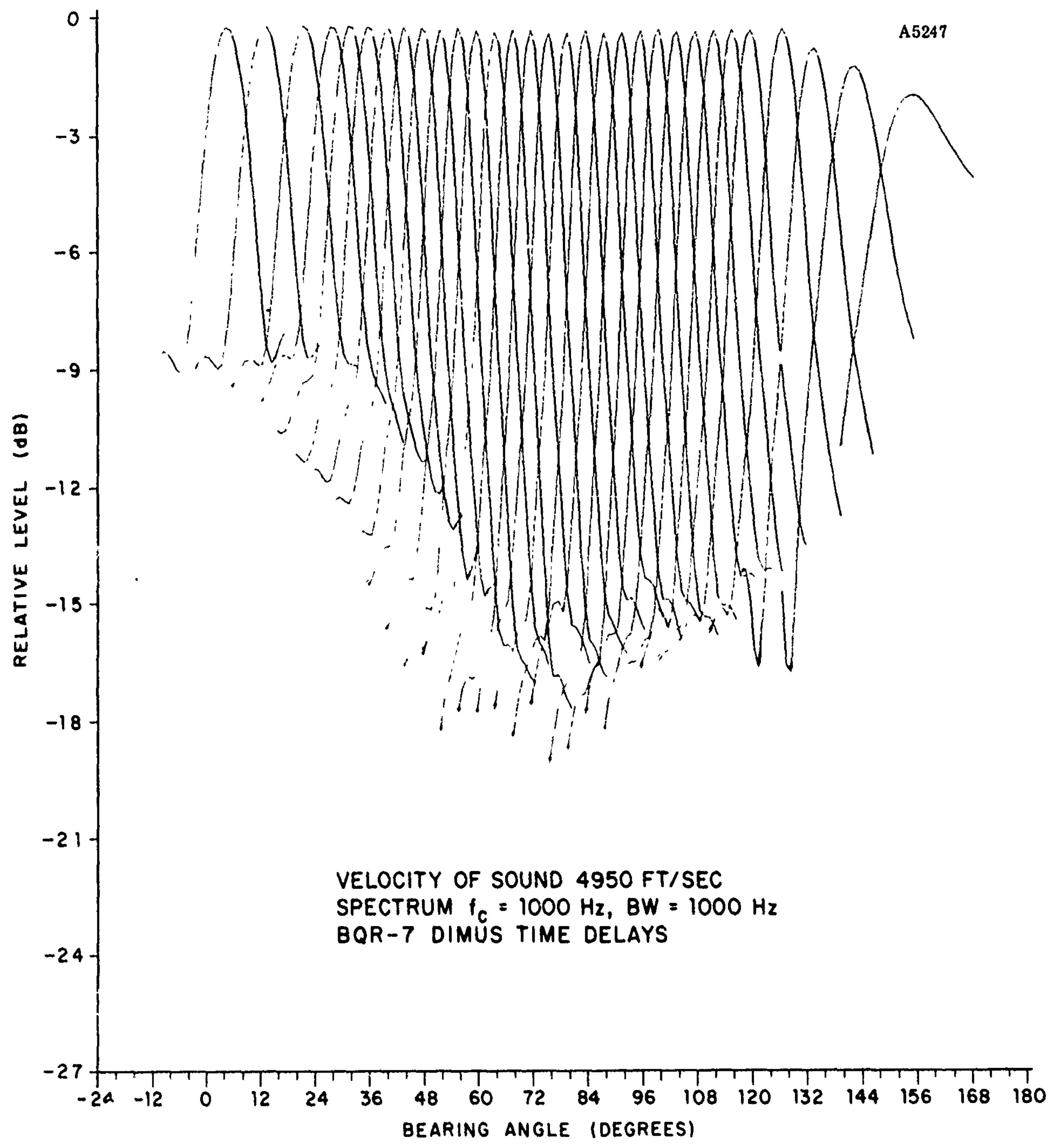

Figure 47. Horizontal Beam Patterns of SS(N) 594 Using a Two-Array Compromise Beamformer Based on SS(N) 594 and SS(N) 671 Configuration

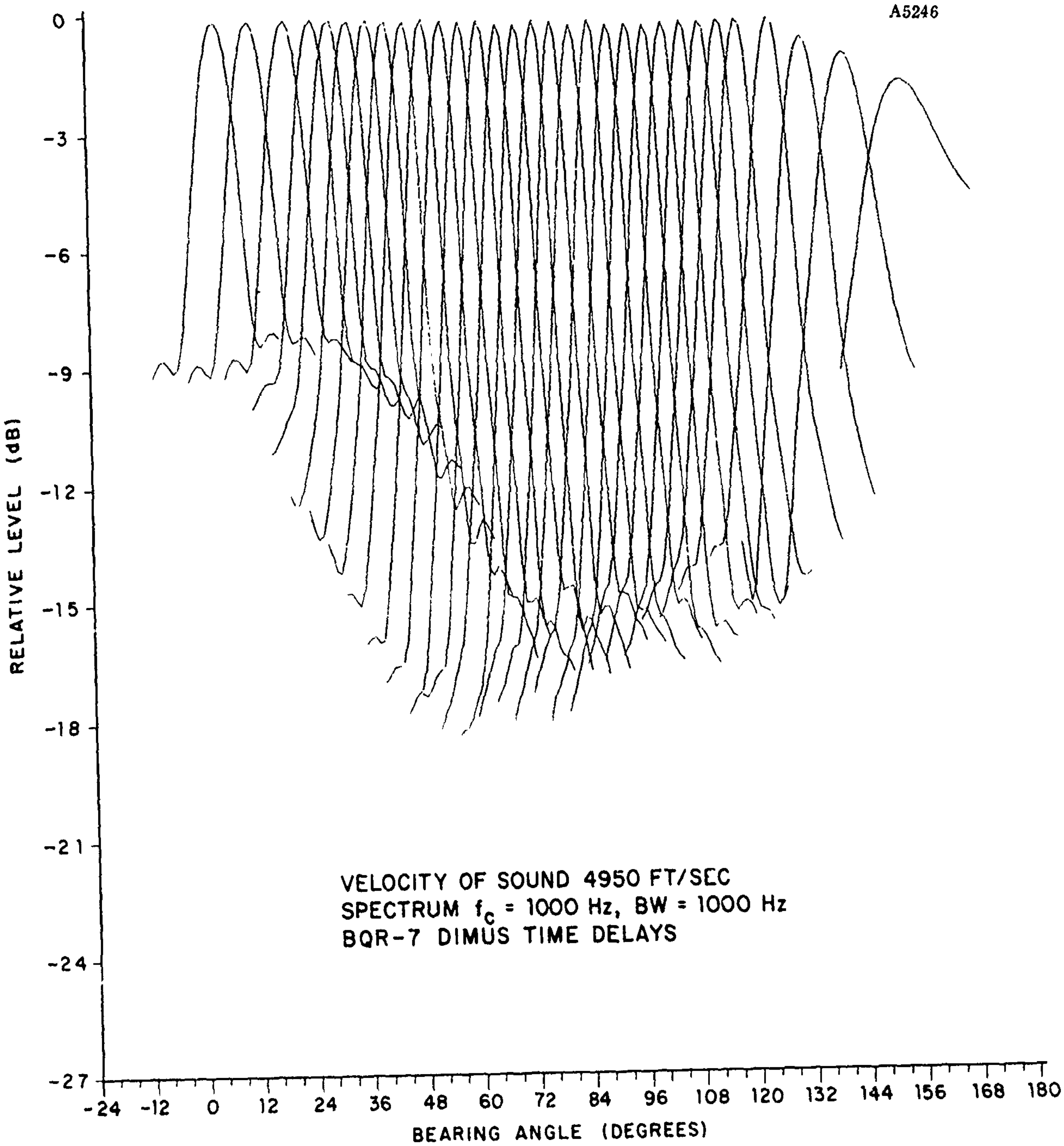

Figure 48. Horizontal Beam Patterns of SS(N) 671 Using a Two-Array Compromise Beamformer Based on SS(N) 594 and SS(N) 671 Configurations

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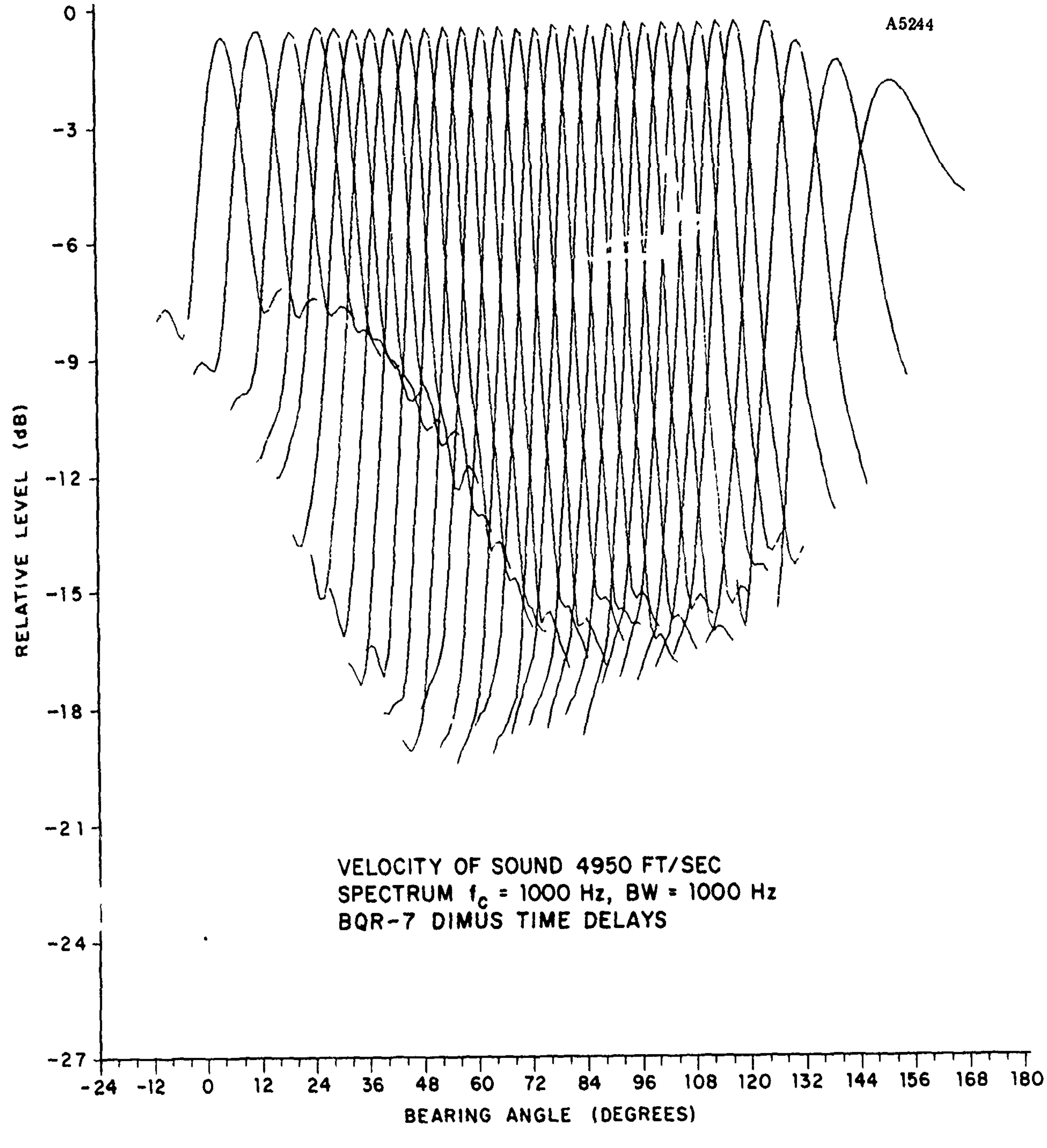

Figure 49. Horizontal Beam Patterns of SSB(N) 608 Using a Two-Array Compromise Beamformer Based on SSB(N) 598 and SSB(N) 608 Configurations

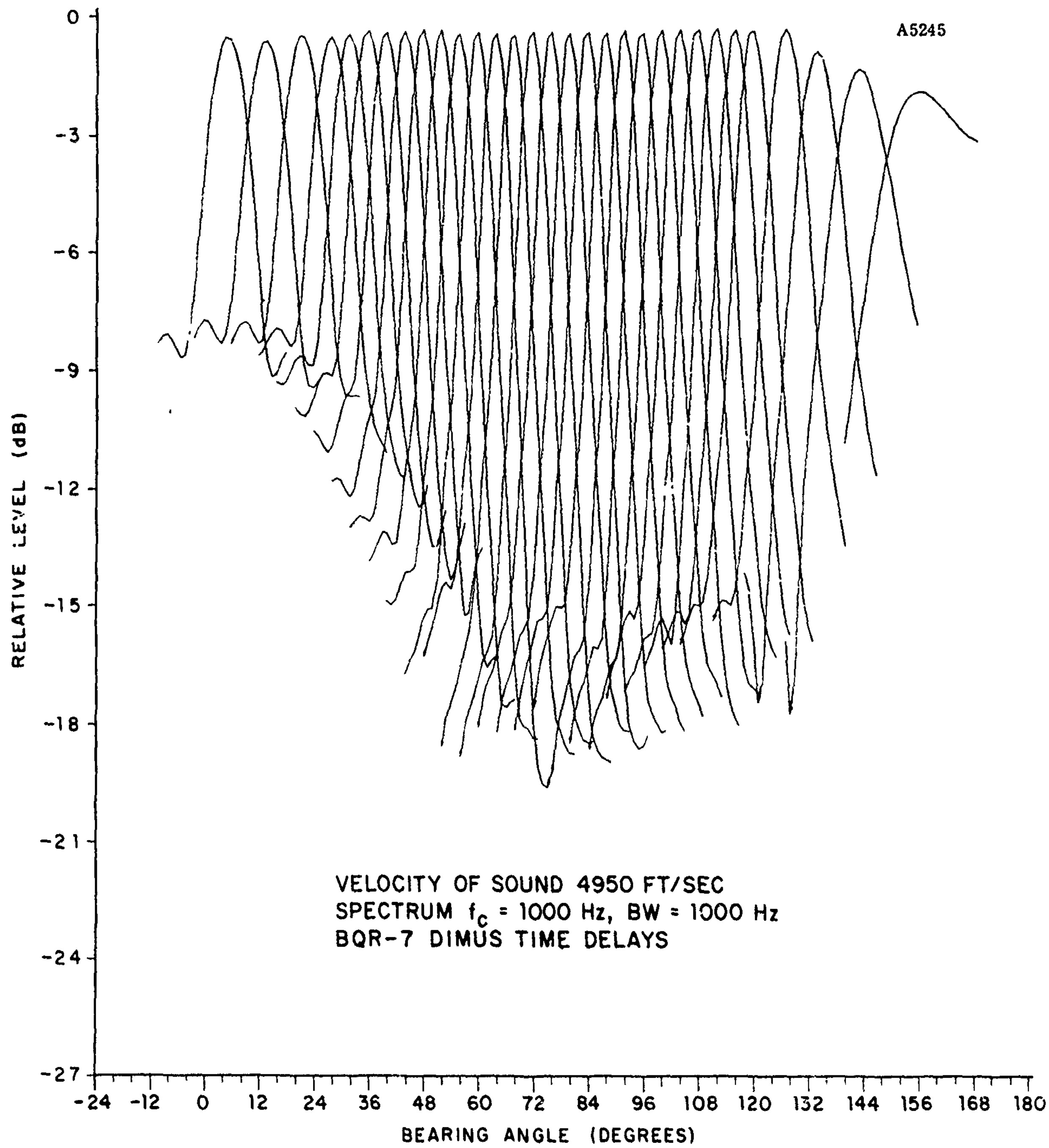

Figure 50. Horizontal Beam Patterns of SSB(N) 598 Using a Two-Array Compromise Beamformer Based on SSB(N) 598 and SSB(N) 608 Configurations

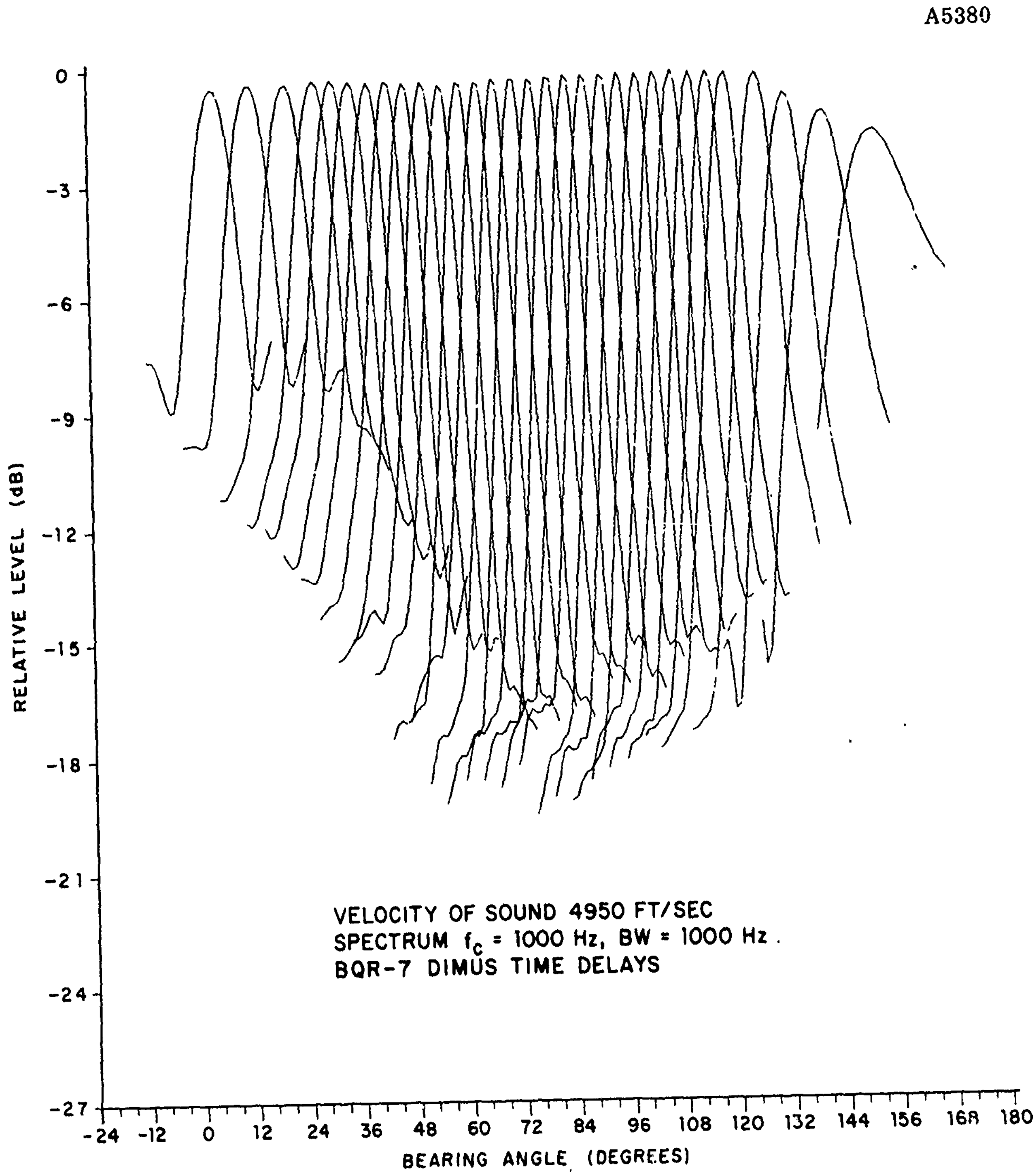

Figure 51. Horizontal Beam Patterns of SS(N) 594 Using a Two-Array Compromise Beamformer Based on SSB(N) 598 and SSB(N) 608 Configurations

TABLE 4

PEAK RESPONSE VALUES FOR VARIOUS TWO-ARRAY COMPROMISES

Beam Number	Gain (dB)											
	Compromise Pairs				Compromise Pairs				Compromise Pairs			
	SSB(N) 608 and	SS(N) 671	SS(N) 594 and	SSB(N) 598	SS(N) 594 and	SSB(N) 608	SSB(N) 598 and	SS(N) 671	SS(N) 594 and	SS(N) 671	SSB(N) 598 and	SSB(N) 608
1	-1.81	-1.84	-1.72	-1.59	-1.77	-1.70	-1.67	-1.88	-1.86	-1.81	-1.71	-1.69
2	-1.23	-1.23	-1.12	-1.18	-1.07	-1.68	-1.31	-1.34	-1.11	-1.09	-1.15	-1.15
3	-0.68	-0.59	-0.66	-0.65	-0.61	-0.59	-0.68	-0.77	-0.65	-0.67	-0.68	-0.62
4	-0.13	-0.13	-0.08	-0.15	-0.05	-0.07	-0.21	-0.21	-0.15	-0.17	-0.11	-0.14
5	-0.16	-0.13	-0.11	-0.11	-0.04	-0.09	-0.32	-0.22	-0.17	-0.20	-0.16	-0.10
6	-0.13	-0.15	-0.10	-0.09	-0.05	-0.05	-0.25	-0.35	-0.18	-0.22	-0.15	-0.11
7	-0.14	-0.16	-0.08	-0.12	-0.10	-0.05	-0.33	-0.37	-0.19	-0.25	-0.14	-0.14
8	-0.21	-0.11	-0.10	-0.12	-0.06	-0.06	-0.34	-0.43	-0.21	-0.23	-0.14	-0.17
9	-0.20	-0.16	-0.13	-0.12	-0.06	-0.07	-0.45	-0.41	-0.24	-0.25	-0.16	-0.16
10	-0.11	-0.27	-0.13	-0.12	-0.06	-0.06	-0.41	-0.56	-0.16	-0.32	-0.16	-0.18
11	-0.16	-0.20	-0.14	-0.14	-0.05	-0.08	-0.56	-0.47	-0.21	-0.28	-0.23	-0.12
12	-0.16	-0.25	-0.13	-0.19	-0.08	-0.05	-0.56	-0.57	-0.24	-0.28	-0.17	-0.20
13	-0.23	-0.14	-0.11	-0.25	-0.07	-0.06	-0.50	-0.50	-0.27	-0.17	-0.24	-0.22
14	-0.21	-0.14	-0.18	-0.20	-0.06	-0.05	-0.54	-0.53	-0.18	-0.27	-0.22	-0.22
15	-0.14	-0.23	-0.12	-0.28	-0.05	-0.08	-0.67	-0.44	-0.27	-0.19	-0.26	-0.21
16	-0.17	-0.20	-0.21	-0.22	-0.07	-0.08	-0.57	-0.59	-0.26	-0.16	-0.20	-0.28
17	-0.16	-0.18	-0.27	-0.18	-0.04	-0.12	-0.61	-0.59	-0.19	-0.26	-0.21	-0.29
18	-0.15	-0.23	-0.21	-0.27	-0.07	-0.08	-0.48	-0.83	-0.18	-0.26	-0.31	-0.21
19	-0.18	-0.15	-0.24	-0.20	-0.07	-0.09	-0.49	-0.63	-0.24	-0.14	-0.25	-0.25
20	-0.14	-0.19	-0.24	-0.22	-0.10	-0.07	-0.66	-0.48	-0.18	-0.17	-0.22	-0.25
21	-0.13	-0.17	-0.21	-0.23	-0.10	-0.07	-0.44	-0.53	-0.14	-0.15	-0.26	-0.24
22	-0.16	-0.08	-0.15	-0.15	-0.12	-0.07	-0.30	-0.36	-0.18	-0.09	-0.16	-0.26
23	-0.17	-0.10	-0.16	-0.19	-0.08	-0.10	-0.27	-0.32	-0.14	-0.16	-0.15	-0.28
24	-0.14	-0.15	-0.23	-0.18	-0.12	-0.07	-0.23	-0.34	-0.14	-0.15	-0.19	-0.26
25	-0.13	-0.13	-0.20	-0.21	-0.07	-0.12	-0.24	-0.31	-0.16	-0.10	-0.23	-0.28
26	-0.11	-0.10	-0.27	-0.16	-0.08	-0.11	-0.28	-0.25	-0.12	-0.11	-0.19	-0.31
27	-0.11	-0.10	-0.23	-0.19	-0.13	-0.06	-0.28	-0.25	-0.10	-0.10	-0.27	-0.27
28	-0.10	-0.11	-0.25	-0.21	-0.11	-0.09	-0.19	-0.33	-0.12	-0.08	-0.36	-0.24
29	-0.12	-0.13	-0.27	-0.22	-0.12	-0.12	-0.29	-0.32	-0.08	-0.08	-0.33	-0.38
30	-0.12	-0.08	-0.20	-0.34	-0.18	-0.13	-0.34	-0.40	-0.09	-0.09	-0.46	-0.34
31	-0.07	-0.09	-0.27	-0.33	-0.08	-0.21	-0.37	-0.46	-0.13	-0.17	-0.36	-0.50

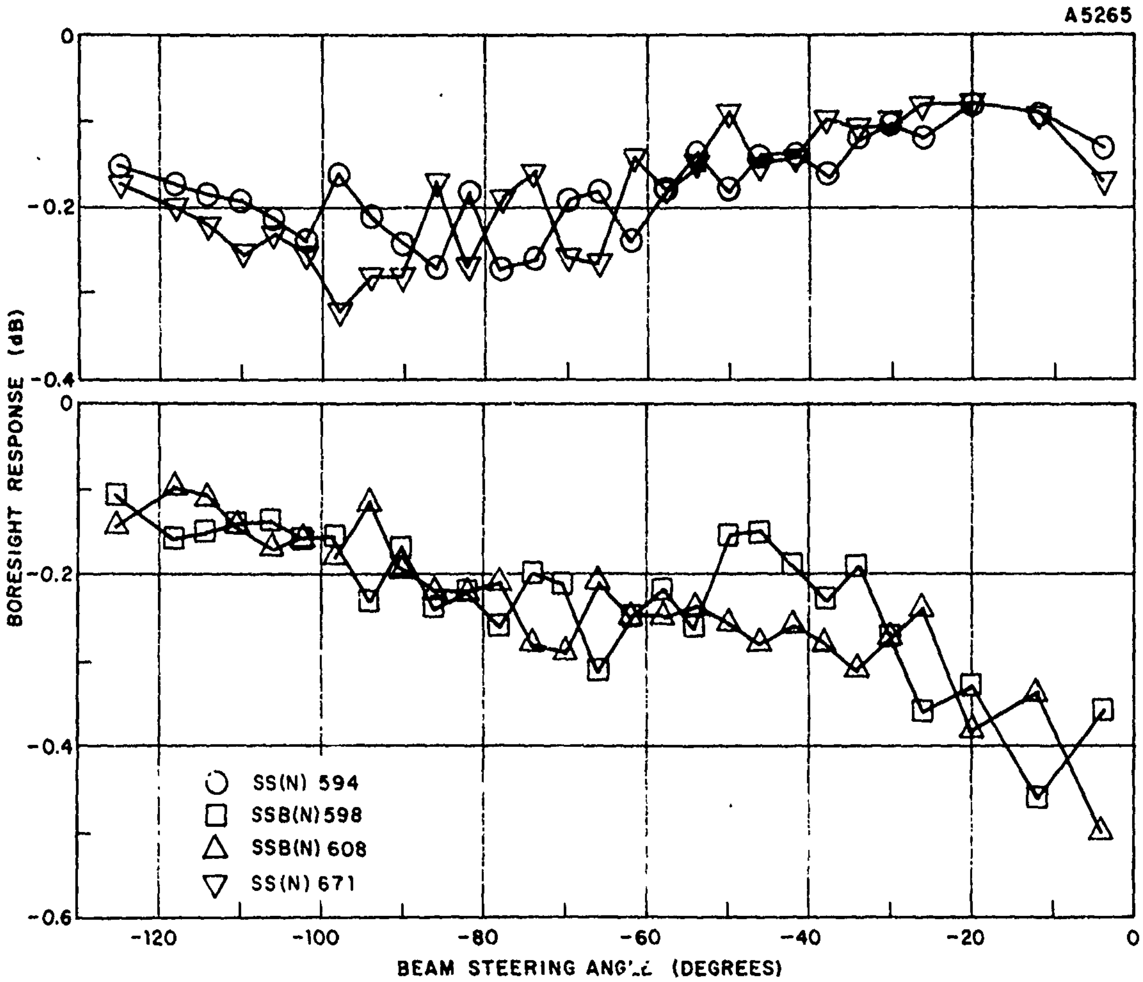

Figure 52. Plot of Peak Response Values for a Two-Array Compromise Between the SS(N) 594 and SS(N) 671 and a Two-Array Compromise Between the SSB(N) 608 and SSB(N) 598 Configurations

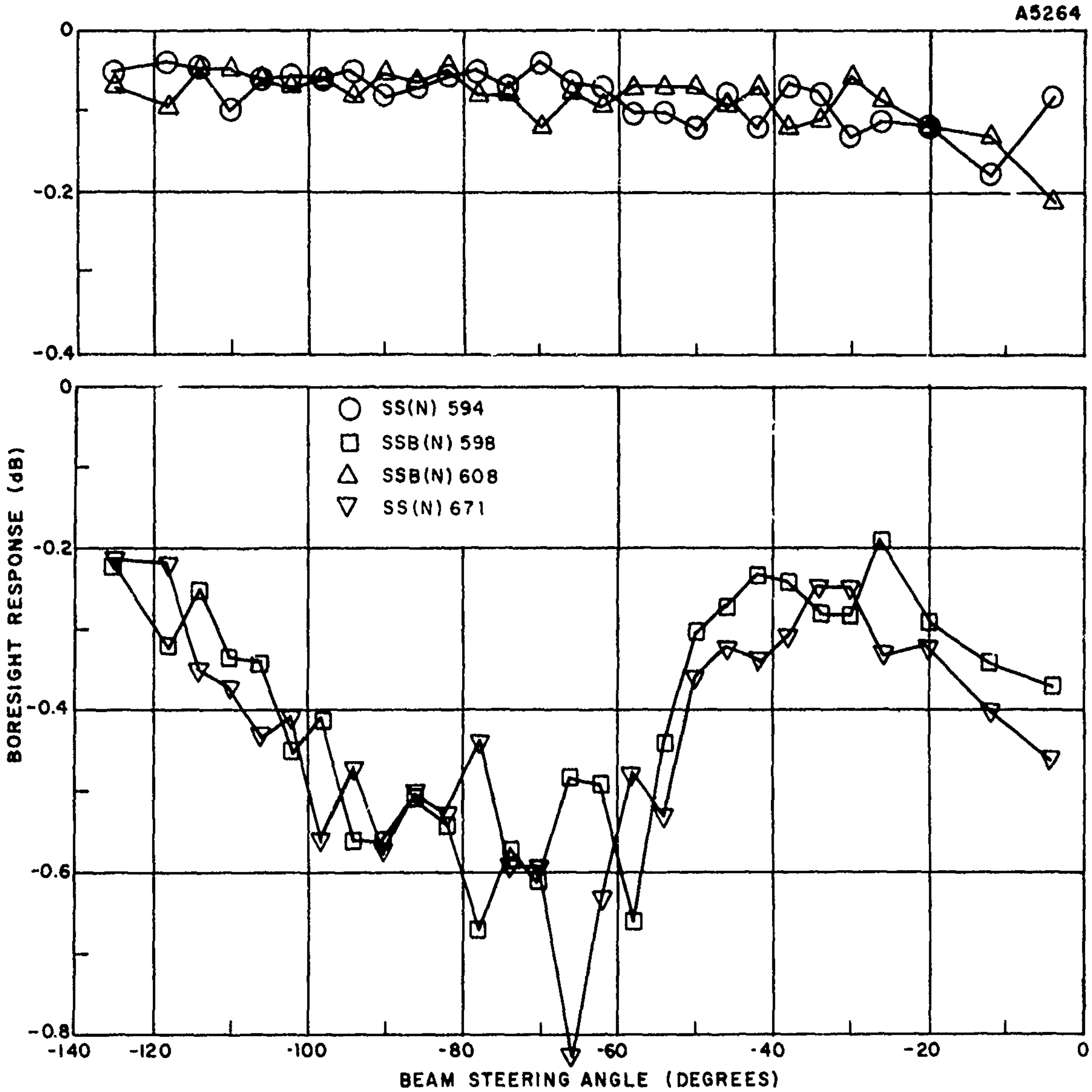

Figure 53. Plot of Peak Response Values for a Two-Array Compromise Between the SS(N) 594 and SSB(N) 608 and a Two-Array Compromise Between the SSB(N) 598 and SS(N) 671 Configurations

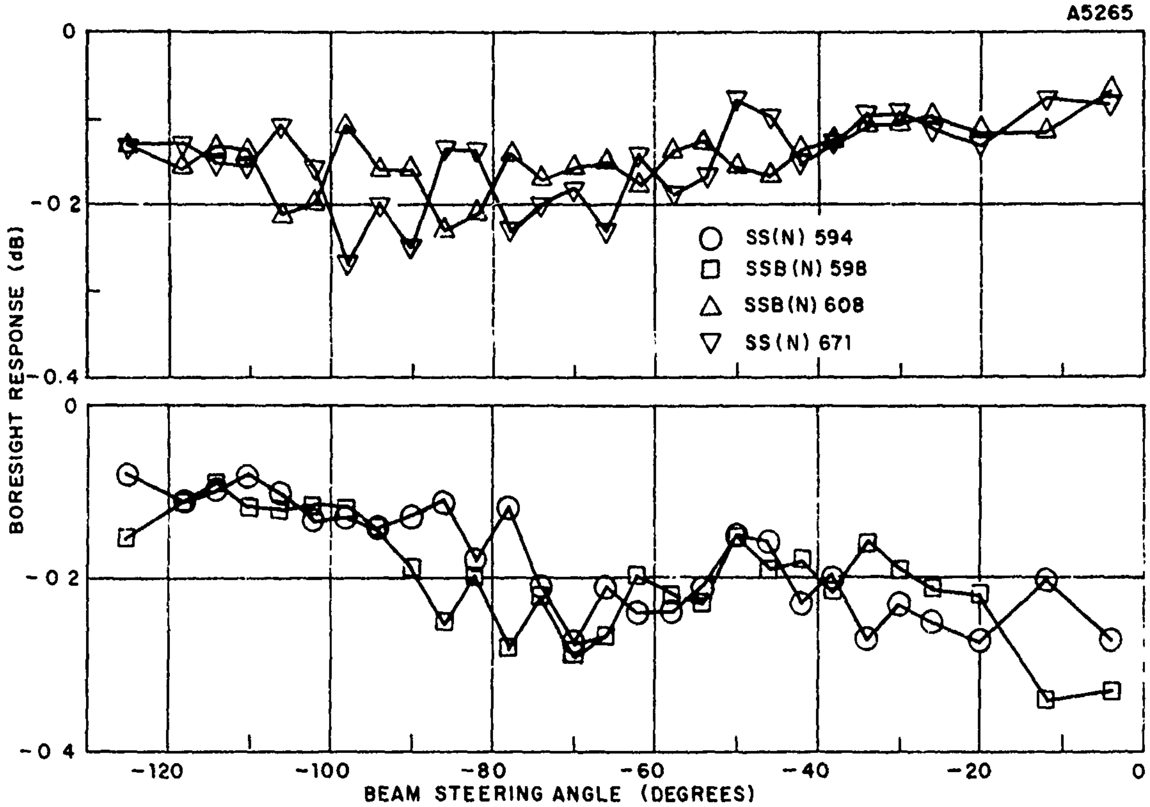

Figure 54. Plot of Peak Response Values for a Two-Array Compromise Between the SSB(N) 608 and SS(N) 671 and a Two-Array Compromise Between the SS(N) 594 and SSB(N) 598 Configurations

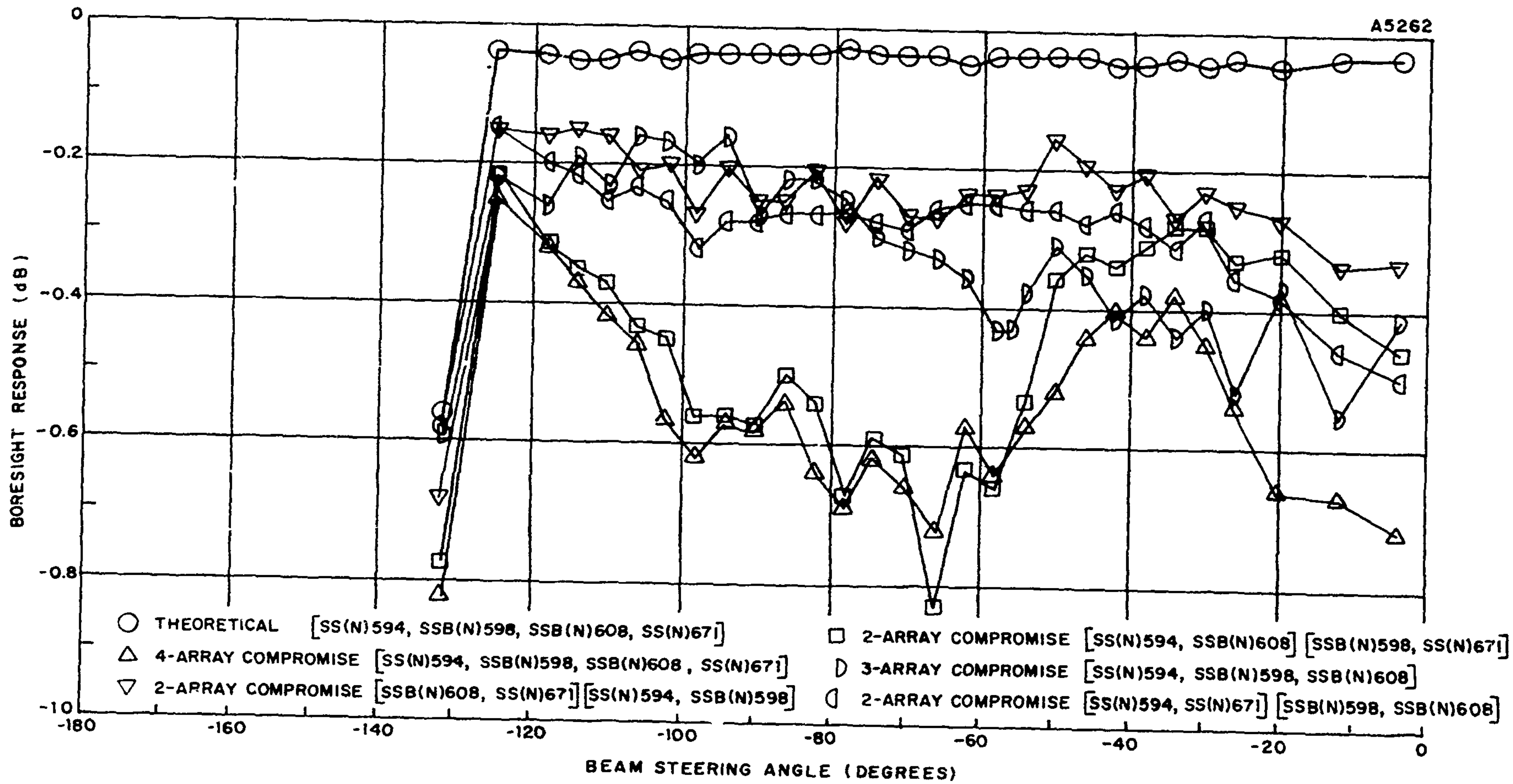

Figure 55. Worst Case Loss in Peak Response Resulting from Various Combinations of Compromise Beamformers

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10
1							1	6	15	20
2			1	6	14	19	26	31	39	44
3	1	6	12	16	22	27	32	37	44	48
4	4	8	13	16	22	26	30	34	40	44
5	10	13	18	20	25	28	32	35	40	43
6	21	24	28	30	34	37	40	42	47	49
7	31	33	36	38	42	44	47	49	53	55
8	41	43	46	47	50	52	54	56	59	61
9	52	54	56	58	60	61	63	65	67	69
10	55	56	58	59	61	62	63	64	66	68
11	70	71	72	73	74	75	76	76	78	79
12	79	79	80	80	81	81	82	82	83	83
13		82	83	83	83	83	83	83	83	83
14		85	85	85	84	83	83	83	82	82
15		89	89	88	87	86	85	84	83	83
16		94	93	92	90	89	87	86	85	84
17		99	98	96	94	92	90	89	87	85
18		103	101	99	96	94	92	90	87	86
19			102	100	97	94	91	89	86	8[illegible]
20			105	103	99	96	93	90	86	84
21				106	101	98	94	92	87	84

2

HYDROPHONE NUMBER

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
15	20	27	33	40	46	52	60	66	73	79	85	92	99	10[illegible]
39	44	50	56	63	69	75	83	89	95	101	108	114	121	10[illegible]
44	48	53	59	64	70	75	82	87	93	98	104	110	117	12[illegible]
40	44	48	53	58	62	67	73	78	83	88	93	98	105	11[illegible]
40	43	47	51	55	59	64	69	73	77	82	86	91	97	10[illegible]
47	49	53	56	60	63	67	71	75	79	83	87	91	96	10[illegible]
53	55	58	61	64	67	71	75	78	82	85	89	93	98	10[illegible]
59	61	64	67	69	72	75	79	82	85	88	91	95	99	10[illegible]
67	69	71	73	76	78	81	84	86	89	92	95	98	102	10[illegible]
66	68	69	71	73	75	77	80	82	84	87	89	92	95	9[illegible]
78	79	80	81	83	84	86	88	90	92	94	96	98	101	10[illegible]
83	83	84	85	86	87	89	90	91	93	94	96	98	101	10[illegible]
83	83	83	84	84	85	86	87	88	89	90	91	93	95	9[illegible]
82	82	82	82	82	82	83	83	84	84	85	86	87	88	9[illegible]
83	83	82	81	81	81	81	81	81	81	81	82	82	83	8[illegible]
85	84	83	82	81	80	80	80	79	79	78	78	78	79	8[illegible]
87	85	84	82	81	80	80	78	77	77	76	75	75	75	7[illegible]
87	86	84	82	80	78	78	76	75	73	72	71	70	70	7[illegible]
86	84	[illegible]	79	77	75	74	72	70	68	66	65	64	63	6[illegible]
86	84	81	78	76	73	72	69	67	65	63	61	59	58	5[illegible]
87	84	81	78	75	72	71	67	64	62	59	57	55	53	5[illegible]

3

HYDROPHONE NUMBER

22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
99	104	110	115	118	120	118	114	109	105	98				
121	103	109	115	120	113	113								
117	122	104	111	117										
105	110	116	122	104										
97	101	107	114	120										
96	101	106	112	119										
98	102	107	113	119										
99	103	108	114	120										
102	106	110	116	122										
95	99	103	108	114										
101	104	108	113	119										
101	103	107	112	117										
95	97	100	105	110	118									
88	90	93	97	102	110									
83	85	87	91	96	103									
79	80	82	85	90	97									
75	76	77	80	85	92									
70	70	71	74	78	85									
63	63	63	65	69	76	82								
58	57	57	59	62	69	75								
53	52	52	53	56	62	68	75							

4

HYDROPHONE NUMBER

HYDRO

34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

Figure 56. Arriv
Subma

5

HYDROPHONE NUMBER

45 46 47 48 49 50 51 52

Figure 56. Arrival Times for SS(N) 594 Class Submarine (Sheet 1)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
22					103	100	96	93	88	85	81	
23						106	102	99	93	90	86	
24							103	99	93	90	85	
-								101	95	91	86	
26									97	93	88	
27										94	89	
28											92	
29												
30												
31												
32												
33												
34												
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												

2

HYDROPHONE NUMBER

11	12	13	14	15	16	17	18	19	20	21	22	23	24
81	78	74	71	69	65	62	59	56	53	51	48	47	46
86	82	78	74	72	68	64	61	58	54	51	49	47	46
85	81	77	73	70	66	62	58	54	51	47	44	42	40
86	82	77	73	70	65	60	56	52	48	45	41	38	36
88	83	78	73	71	65	60	56	51	47	43	39	36	34
89	83	78	73	70	64	59	54	49	45	40	36	33	30
92	87	81	76	72	66	61	56	51	46	41	36	33	29
	88	82	76	72	66	60	54	49	44	38	33	29	25
		83	77	73	66	60	54	48	42	36	30	26	21
			81	77	69	63	56	50	44	38	31	26	21
			88	83	75	69	62	56	50	43	36	31	25
				89	81	75	68	62	55	49	41	36	30
					88	82	75	69	62	55	48	42	36
						86	79	73	66	60	52	47	40
							82	76	70	63	56	50	44
								81	75	68	61	55	49
									73	67	60	54	48
										60	53	48	41
											59	53	47
												74	68
													77

3

HYDROPHONE NUMBER

HYDROPHON

	24	25	26	27	28	29	30	31	32	33	34	35	36	37	3
	46	47	50	56	62	68	74								
	46	46	48	54	60	66	73	78							
	40	40	42	47	53	59	66	71	78						
	36	36	37	42	48	54	60	66	73	79					
	34	32	33	38	43	50	56	62	69	75	81				
	30	28	29	33	38	44	51	56	63	70	76	82			
	29	27	27	31	36	42	48	54	61	68	74	80	86		
	25	22	22	25	29	35	41	47	54	61	67	73	80	86	
6	21	18	16	18	22	28	33	39	46	52	59	65	72	78	
6	21	17	14	16	19	24	29	34	41	47	54	60	66	73	
1	25	20	17	17	20	24	29	33	40	46	52	58	64	70	
6	30	24	20	20	21	24	29	33	39	45	50	56	62	68	
2	36	30	25	24	25	27	31	34	40	45	50	55	61	66	
7	40	34	29	27	27	29	32	35	40	44	49	54	59	64	
0	44	37	32	29	29	30	33	36	40	45	49	54	58	63	
5	49	42	37	34	33	34	36	39	43	47	51	55	59	64	
4	48	41	35	32	31	31	33	35	39	42	46	50	54	58	
8	41	35	29	25	23	23	25	27	30	33	36	40	43	47	
3	47	40	34	30	28	27	28	30	32	35	38	41	45	48	
74	68	61	55	51	48	47	48	49	51	53	56	59	62	65	
	77	70	64	59	56	55	55	56	57	59	61	64	66	69	
		76	70	65	61	50	59	60	61	62	64	66	68	70	
		86	79	74	70	68	67	67	68	69	70	72	73	75	

4

YDROPHONE NUMBER — HYDROPHONE NUMBER

7	38	39	40	41	42	43	44	45	46	47	48	49	50	51
86														
78	86													
73	80	86												
70	78	84												
68	75	81	87											
66	73	78	84	90										
64	70	75	81	86	91									
63	69	74	79	84	89	94								
64	69	74	79	83	88	93	97							
58	63	68	72	76	81	85	89	95						
47	52	56	60	64	68	72	76	82	85					
48	52	56	60	63	67	71	74	79	83	87				
65	68	72	75	78	82	85	88	93	96	100	103			
69	72	75	78	81	84	87	90	94	97	100	103	107		
70	73	76	78	81	83	86	88	92	94	97	100	104	106	
75	77	80	82	84	86	88	90	93	95	98	100	103	106	

Figure 56. Arrival Times for SS(N) 594 Cla
Submarine (Sheet 2)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11
45											
46											
47											
48											
49											
50											
51											
52											
53											
54											
55											
56											
57											
58											
59											
60											
61											
62											

2

HYDROPHONE NUMBER

10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

102 108 113 117

3

HYDROPHONE NUMBER

	24	25	26	27	28	29	30	31	32	33	34	35	36	37
			81	76	72	69	68	67	68	68	69	70	71	73
			91	86	81	78	76	76	75	75	76	76	77	78
			96	91	86	82	80	79	78	78	78	78	78	79
			105	99	94	90	88	86	85	84	83	83	83	83
			110	105	99	95	92	90	88	87	86	85	85	84
			114	108	102	98	94	92	90	88	87	85	84	83
				117	111	106	103	100	97	95	93	92	90	89
				118	112	106	102	99	96	93	91	89	87	85
				119	113	108	103	100	96	93	90	88	85	83
				120	114	108	103	99	95	92	89	86	83	80
				118	111	105	100	96	92	88	84	81	78	75
				120	114	108	102	98	93	89	85	81	78	74
				120	114	107	102	97	92	87	83	79	75	71
				120	113	107	101	96	90	85	81	76	72	67
				104	122	115	109	104	97	92	86	81	76	71
				120	114	107	124	119	112	106	100	94	89	83
		114	114	123	118	112	105	123	116	110	103	97	90	84
13	117	121	123	123	119	114	108	103	96	89	83	76	70	63

HYDROPH

4

HYDROPHONE NUMBER

36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
71	73	74	76	78	80	81	83	85	87	89	91	93	96	98
77	78	79	81	82	83	84	86	87	89	90	92	93	96	97
78	79	79	81	81	82	83	84	85	86	87	88	89	91	92
83	83	83	84	84	84	85	85	86	86	87	88	88	90	90
85	84	84	84	84	84	84	84	84	84	84	84	85	85	8[illegible]
84	83	82	83	82	81	81	80	80	79	79	79	79	79	79
90	89	87	87	86	85	84	83	82	81	80	80	79	79	7[illegible]
87	85	83	83	81	79	78	77	76	74	73	72	71	70	69
85	83	81	80	78	76	74	72	70	68	67	65	64	62	61
83	80	77	76	74	71	69	67	65	62	60	58	56	54	53
78	75	71	70	67	64	61	58	56	53	51	48	46	43	41
78	74	70	68	65	62	59	55	53	49	47	44	41	38	3[illegible]
75	71	67	65	61	57	54	50	47	43	40	37	34	30	27
72	67	62	59	55	51	47	43	39	34	31	27	24	19	1[illegible]
76	71	65	62	5[illegible]	52	47	43	39	32	29	24	20	14	11
89	83	76	73	67	61	56	50	46	39	34	29	24	17	1[illegible]
90	84	76	72	65	59	52	46	41	32	27	21	15	7	[illegible]
70	63	55	51	44	37	31	24	19	10	4				

Figure 56. Arrival Times for
Submarine (Sheet

5

HYDROPHONE NUMBER

46	47	48	49	50	51	52
89	91	93	96	98	101	
90	92	93	96	97	100	
87	88	89	91	92	94	
87	88	88	90	90	92	
84	84	85	85	86	87	
79	79	79	79	79	80	
80	80	79	79	78	79	79
73	72	71	70	69	69	68
67	65	64	62	61	61	60
60	58	56	54	53	52	50
51	48	46	43	41	40	38
47	44	41	38	36	34	31
40	37	34	30	27	25	22
31	27	24	19	16	13	10
29	24	20	14	11	7	3
34	29	24	17	13	9	4
27	21	15	7	2		
4						

Figure 56. Arrival Times for SS(N) 594 Class Submarine (Sheet 3)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11
1							41	56	75	90	107
2			0	16	34	49	66	81	99	114	7
3	101	116	12	26	42	57	72	87	104	118	10
4	104	118	13	26	42	56	70	84	100	114	4
5	110	123	18	30	45	58	72	85	100	113	3
6	121	10	28	40	54	67	80	92	107	119	9
7	7	19	36	48	62	74	87	99	113	1	14
8	17	30	46	57	70	82	94	106	119	7	20
9	28	41	56	68	80	91	103	115	3	15	27
10	31	43	58	69	81	92	103	114	2	14	25
11	47	58	72	83	94	105	116	2	14	25	36
12	56	66	80	90	101	111	122	8	19	29	40
13		69	83	93	103	113	123	9	19	29	39
14		72	95	95	104	113	123	9	18	28	38
15		76	89	98	107	116	1	10	19	29	38
16		81	93	102	110	119	3	12	21	30	39
17		86	98	106	114	122	6	15	23	31	40
18		90	101	109	116	0	8	16	23	32	40
19			102	110	117	0	7	15	22	30	37
20			105	113	119	2	9	16	22	30	37
21				116	121	4	10	18	23	30	37

2

HYDROPHONE NUMBER

	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	107	0	17	33	52	70	86	103	119	12	29	46	61	77
4	7	23	40	56	75	93	109	1	18	35	51	68	60	76
18	10	26	41	57	75	92	107	123	15	31	47	64	79	71
14	4	20	35	49	67	83	98	113	4	20	35	52	67	83
13	3	18	32	46	64	79	93	107	122	12	28	44	58	74
19	9	23	37	50	67	81	95	109	123	13	28	43	58	73
1	14	28	41	54	71	85	98	112	1	15	30	45	59	74
7	20	34	46	59	75	89	102	115	4	17	32	46	60	75
15	27	40	53	65	81	94	106	119	8	21	35	49	63	77
14	25	38	50	62	77	90	102	114	3	15	28	42	56	70
25	36	48	60	71	86	98	110	122	10	22	34	48	61	75
29	40	52	63	74	89	100	111	123	10	22	34	48	60	74
29	39	51	61	72	86	97	108	119	6	17	29	41	54	67
28	38	48	59	69.	83	93	104	114	1	12	23	34	46	60
29	38	47	58	66	81	91	101	111	121	8	18	29	41	53
30	39	48	57	67	80	90	99	109	118	4	14	25	36	48
31	40	48	57	67	80	88	97	107	116	1	11	21	32	43
32	40	48	56	64	78	86	95	103	112	121	6	16	26	37
30	37	45	53	61	74	82	90	98	106	115	0	9	19	29
30	37	44	52	59	71	79	87	95	103	111	119	4	13	23
30	37	44	51	58	70	76	84	92	99	107	115	123	8	18

3

HYDROPHONE NUMBER

HYDROPHONE NUM

	24	25	26	27	28	29	30	31	32	33	34	35	36	37
61	77	92	105	120	5	11	16	22	25					
60	76	92	107	113	123									
79	71	88	104											
67	83	99	91											
58	74	91	107											
58	73	89	106											
[illegible]9	74	90	106											
60	75	91	107											
63	77	93	109											
36	70	85	101											
61	75	90	106											
60	74	89	104											
54	67	82	97	118										
40	60	74	89	110										
41	53	68	83	103										
36	48	62	77	97										
32	43	56	72	92										
26	37	50	64	85										
19	29	41	55	76	92									
13	23	35	48	68	85									
8	18	29	42	61	77	95								

/ 4

NUMBER

HYDROPHONE NUMBER

38 39 40 41 42 43 44 45 46 47 48 49 50 51

Figure 57. Sampling Times for SS(N) 594 C
Submarine (Sheet 1)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11
22					123	6	12	19	24	31	37
23						12	18	25	29	36	42
24							19	25	29	36	41
25								27	31	37	42
26									33	39	44
27										40	45
28											48
29											
30											
31											
32											
33											
34											
35											
36											
37											
38											
39											
40											
41											
42											
43											
44											

2

HYDROPHONE NUMBER

11	12	13	14	15	16	17	18	19	20	21	22	23	24
37	44	50	57	68	74	81	89	96	103	111	118	3	12
42	48	54	60	71	77	83	91	98	104	111	119	3	12
41	47	53	59	69	75	81	87	94	101	107	114	122	6
42	48	53	59	69	74	79	85	91	98	105	111	118	2
44	49	54	59	70	74	79	85	90	96	103	109	116	0
45	49	54	59	69	73	78	83	88	94	99	106	113	120
48	53	57	62	71	75	80	85	90	95	100	105	113	119
	54	58	62	71	75	79	83	88	93	97	102	108	115
		59	63	72	75	79	83	87	91	95	99	105	110
			67	76	78	82	85	89	93	97	100	105	110
			74	82	84	88	91	95	99	102	105	110	114
				88	90	94	97	101	104	108	110	115	119
					97	101	104	108	111	114	117	121	1
						105	108	112	115	119	121	2	5
							111	115	119	122	1	5	9
								120	0	3	6	10	14
									122	2	5	[illegible]	13
										119	122	3	6
											4	8	12
												29	33
													43

3

HYDROPHONE NUMBER

HYDROPHONE NU

	24	25	26	27	28	29	30	31	32	33	34	35	36	37
3	12	23	36	55	71	88	104							
3	12	22	34	53	69	85	103	118						
2	6	16	28	46	62	78	96	111	4					
8	2	12	23	41	57	73	89	106	123	15				
6	0	8	19	37	52	69	85	102	119	11	27			
3	120	4	15	32	47	63	80	95	113	6	22	38		
3	119	3	13	30	45	61	77	93	111	4	20	36	52	
8	115	122	8	24	38	54	70	86	103	121	13	29	46	62
05	110	118	2	17	31	47	62	78	95	111	5	21	38	54
05	110	116	0	15	28	43	58	73	90	106	0	16	32	49
10	114	119	3	16	29	43	58	72	89	105	121	14	30	46
15	119	123	6	19	30	43	58	72	88	104	119	12	28	44
121	1	5	11	23	34	46	60	73	89	104	119	11	27	42
2	5	9	15	26	36	48	61	74	89	103	118	9	25	40
5	9	12	18	28	38	49	62	75	89	104	118	9	24	39
10	14	17	23	33	42	53	65	78	92	106	120	10	25	40
9	13	16	20	31	40	50	62	74	88	101	115	5	19	34
3	6	10	14	23	32	42	54	66	79	92	105	119	8	22
8	12	15	19	28	37	46	57	69	81	94	107	120	10	23
29	33	37	41	50	57	66	77	88	100	112	1	14	27	41
	43	46	50	58	65	74	84	95	106	118	6	19	31	45
		52	56	64	70	79	88	99	110	121	9	21	33	46
		62	65	73	79	87	96	106	117	4	15	27	38	51

NUMBER	HYDROPHONE NUMBER													
	38	39	40	41	42	43	44	45	46	47	48	49	50	51
62														
54	72													
49	66	85												
46	64	83												
44	61	80	96											
42	59	77	93	109										
40	56	74	90	105	120									
39	55	73	88	103	118	9								
40	55	73	88	102	117	8	23							
34	49	67	81	95	110	0	14	31						
22	38	55	69	83	97	111	1	17	31					
23	38	55	69	82	96	110	123	14	28	43				
41	54	71	84	97	111	0	13	28	42	56	69			
45	58	74	87	100	113	2	15	29	43	56	69	83		
46	59	75	87	100	112	1	13	27	39	53	66	80	92	
51	63	79	91	103	115	3	15	28	40	54	66	79	92	

Figure 57. Sampling Times for SS(N) 594 (
Submarine (Sheet 2)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
45												
46												
47												
48												
49												
50												
51												
52												
53												
54												
55												
56												
57												
58												
59												
60												
61												
62												

2

HYDROPHONE NUMBER

11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

37 53 68 82

3'

HYDROPHONE NUMBER

HYDROPHONE NUMBER

	25	26	27	28	29	30	31	32	33	34	35	36	37	38
		67	75	81	88	97	106	117	3	14	25	36	48	60
		77	85	90	97	105	115	0	10	21	31	42	53	65
		82	90	95	101	109	118	3	13	23	33	43	54	65
		91	98	103	109	117	1	10	19	28	38	48	58	69
		96	104	108	114	121	5	13	22	31	40	50	59	70
		100	107	111	117	123	7	15	23	32	40	49	58	67
			116	120	1	8	15	22	30	38	47	55	64	72
			117	121	1	7	14	21	28	36	44	52	60	68
			118	122	3	8	15	21	28	35	43	50	58	66
			119	123	3	8	14	20	27	34	41	48	55	62
			117	120	0	5	11	17	23	29	36	43	50	56
			119	123	3	7	13	18	24	30	36	43	49	55
			119	123	2	7	12	17	22	28	34	40	46	52
			119	122	2	6	11	15	20	26	31	37	42	47
			102	7	10	14	19	22	27	31	36	41	46	50
			119	123	2	29	34	37	41	45	49	54	58	61
	89	99	122	3	7	10	38	41	45	48	52	55	59	61
82	96	108	122	4	9	13	18	21	24	28	31	35	38	40

4

BER	HYDROPHONE NUMBER													
38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
60	75	87	99	110	122	10	22	34	46	59	72	84	100	
65	80	91	102	113	1	12	24	35	47	59	72	83	99	
65	80	90	101	112	123	10	21	32	43	54	67	78	93	
69	83	93	103	114	0	11	21	32	43	53	66	76	91	
70	83	93	103	113	123	9	19	29	39	50	60	72	86	
67	82	91	100	110	119	5	14	24	34	44	54	64	79	
72	86	95	104	113	122	7	16	25	35	44	54	63	78	8
68	82	90	98	107	116	1	9	18	27	36	45	54	67	7
66	78	87	95	103	111	119	3	12	20	29	37	46	59	6
62	74	82	90	98	106	114	121	5	13	21	29	38	50	5
56	68	75	82	89	97	105	112	120	3	11	18	26	38	4
55	66	73	80	87	93	102	108	116	123	6	13	21	32	3
52	63	69	75	82	88	95	102	109	116	123	5	12	23	3
47	57	63	69	75	81	87	92	99	106	113	118	1	11	1
50	60	65	70	75	81	87	90	97	102	109	113	120	5	1
61	71	75	79	84	88	94	97	102	107	113	116	122	7	1
61	70	73	77	80	84	89	90	95	99	103	105	110		
40	49	52	55	59	62	67	68	72						

Figure 57. Sampling Times for SS(N) 594 Clas
Submarine (Sheet 3)

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HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
1	0	5	12	19	24	30	36	41	48	54	60	66
2	0	5	11	17	22	27	32	37	43	48	54	59
3	0	4	10	16	19	24	29	33	39	43	48	53
4	1	5	10	15	18	22	26	30	35	39	44	48
5	12	15	20	24	27	30	34	37	41	45	49	52
6	19	21	25	29	32	35	38	41	45	48	51	55
7	28	30	34	37	40	42	45	48	51	54	57	60
8	31	33	36	39	41	43	46	48	51	53	56	58
9	47	48	51	53	55	57	59	61	63	65	67	70
10	56	57	59	61	62	64	65	67	69	70	72	74
11	66	67	69	70	71	72	73	74	76	77	78	80
12	77	77	79	79	80	81	82	82	83	84	85	86
13		80	81	81	81	82	82	82	83	83	83	84
14.		82	83	82	82	82	82	82	82	82	82	82
15		91	91	90	90	89	88	88	87	87	86	86
16		92	91	90	89	88	87	86	85	84	83	82
17		96	96	93	92	91	89	88	86	85	84	82
18		100	99	96	95	93	91	89	87	85	84	82
19			103	99	98	95	93	91	88	86	84	82
20			113	109	107	104	102	99	96	94	91	88
21				107	105	101	98	96	92	89	86	83

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HYDROPHONE NUMBER

12	13	14	15	16	17	18	19	20	21	22	23	24	25
66	72	77	86	91	97	103	109	116	122	105	111	118	115
59	65	69	78	82	86	94	99	105	111	118	121	107	114
53	58	62	70	74	79	84	89	94	100	106	112	119	102
48	52	56	63	67	71	76	81	85	90	96	102	109	116
52	56	59	66	69	73	77	81	85	90	95	101	107	114
55	58	61	67	70	73	77	81	85	89	94	100	105	112
60	63	66	71	74	77	80	84	87	91	95	101	106	112
58	61	63	68	70	73	76	79	82	86	89	95	100	106
70	72	74	78	80	82	85	88	90	93	97	102	107	112
74	76	77	81	83	85	87	89	91	94	97	102	106	111
80	81	82	85	87	88	90	92	94	96	98	103	107	112
86	87	88	90	91	92	93	95	96	98	100	105	108	112
84	84	85	87	87	88	89	90	91	92	94	98	101	105
82	82	82	83	83	84	84	85	85	86	87	91	93	97
86	86	85	86	86	86	86	86	86	86	87	90	92	95
82	81	81	81	80	80	79	79	79	73	78	82	83	85
82	81	80	80	79	78	77	76	75	75	74	77	78	80
82	80	79	78	76	75	74	72	71	70	69	71	72	73
82	80	78	76	75	73	71	69	68	66	65	67	66	67
88	86	84	82	80	77	75	73	71	69	67	68	68	68
83	80	78	75	73	70	67	65	62	60	57	58	57	57

3

HYDROPHONE NUMBER

HYDROPHONE NU

25	26	27	28	29	30	31	32	33	34	35	36	37	38
115	120												
114	120												
102	108												
116	122												
114	119												
112	117												
112	118												
106	111												
112	118												
111	116												
112	117												
112	117												
105	109	119											
97	101	111											
95	99	109											
85	89	99											
80	83	93											
73	76	86											
67	70	79	85										
68	70	79	85										
57	59	67	73	80									

4

ɒPHONE NUMBER

HYDROPHONE NUMBER

38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

Figure 58. Arrival Times for SSB(N) 598 Class Submarine (Sheet 1)

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HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
22					106	103	99	96	92	89	85	82
23						110	106	103	98	95	91	87
24							108	104	99	95	91	87
25								107	101	97	92	88
26									102	97	92	88
27										105	100	95
28											96	91
29												103
30												
31												
32												
33												
34												
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												

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2

HYDROPHONE NUMBER

12	13	14	15	16	17	18	19	20	21	22	23	24	25
82	79	76	73	70	67	64	61	58	55	52	53	51	51
87	83	80	77	74	70	67	63	60	57	53	53	51	50
87	83	79	75	72	68	64	60	57	53	49	49	46	45
88	84	80	75	72	67	63	59	55	51	47	46	43	41
88	83	79	74	70	65	61	57	52	48	43	42	38	36
95	90	86	80	76	71	66	62	57	52	47	45	41	38
91	86	81	76	71	66	61	56	51	46	40	38	34	30
103	98	93	87	82	77	71	66	60	55	49	46	41	37
	90	85	78	73	67	61	55	49	44	37	33	28	23
		99	92	86	80	74	68	62	56	48	44	38	32
		96	89	83	77	70	64	58	51	44	39	32	26
			89	84	77	71	64	58	51	44	38	31	24
				89	83	77	70	64	57	50	44	36	29
					81	75	68	62	56	48	42	35	27
						80	73	67	61	54	47	40	32
							69	63	57	50	43	36	28
								75	69	62	55	48	40
									70	63	57	50	42
										70	63	56	49
											86	79	72
												80	73
													78
													85

3

HYDROPHONE NUMBER

HYDROPHONE NUMB

25	26	27	28	29	30	31	32	33	34	35	36	37	38
51	52	60	66	73	80								
50	51	59	65	72	79	85							
45	45	52	58	65	72	79	86						
41	41	48	53	61	68	74	81	87					
36	35	42	47	54	62	68	75	81	87				
38	38	43	49	56	63	69	77	83	89	95			
30	29	34	39	47	54	60	67	73	80	85	92		
37	35	39	44	51	58	64	72	78	84	90	97	103	
23	20	23	27	34	41	46	54	60	66	73	79	85	91
32	29	30	34	40	47	52	59	65	71	78	84	90	95
26	22	22	25	31	37	41	48	54	60	66	72	78	83
24	20	19	21	26	31	35	41	47	53	58	64	70	75
29	24	22	23	27	32	35	41	46	51	56	62	67	72
27	22	19	20	23	27	29	35	39	44	49	54	59	63
32	27	23	24	26	30	32	37	41	46	50	55	60	64
28	23	18	18	21	24	25	30	34	38	42	47	51	55
40	35	30	29	31	34	35	39	43	47	51	55	59	62
42	36	31	30	31	34	34	38	41	45	48	52	56	59
49	43	37	36	37	39	39	42	45	48	51	55	58	61
72	66	60	58	58	60	59	62	65	67	70	73	76	79
73	67	60	58	58	59	58	60	62	65	67	70	72	74
78	72	65	63	62	63	61	63	65	67	69	71	73	75
85	79	72	69	68	68	66	67	69	70	72	73	75	77

4

HYDROPHONE NUMBER

ROPHONE NUMBER

38	39	40	41	42	43	44	45	46	47	48	49	50	51	5
91														
95	105													
83	92													
75	83	88												
72	80	84	90											
63	71	75	80	85										
64	71	75	80	85	90									
55	62	66	70	75	79	84								
62	69	72	76	81	85	89	94							
59	65	68	72	76	80	84	89	92						
61	66	69	73	76	80	83	88	91	95					
79	84	86	89	93	96	99	103	106	109	113				
74	79	81	84	87	90	92	96	98	101	104	106			
75	79	81	83	85	88	90	93	95	98	101	102	106		
77	80	81	83	85	87	89	92	94	96	98	101	103		

Figure 58. Arrival Times for SSB(N) 598 Clas Submarine (Sheet 2)

HYDROPHONE NUMBER

BEAM NUMBER

	1	2	3	4	5	6	7	8	9	10	11	12
45												
46												
47												
48												
49												
50												
51												
52												
53												
54												
55												
56												
57												
58												
59												
60												
61												
62												

2

HYDROPHONE NUMBER

12 13 14 15 16 17 18 19 20 21 22 23 24 25 2

3

HYDROPHONE NUMBER

26	27	28	29	30	31	32	33	34	35	36	37	38	39
87	79	76	74	74	71	72	73	74	75	76	78	79	8
92	84	80	78	77	74	75	75	76	76	77	78	79	8
98	90	86	84	82	79	79	79	79	79	79	80	80	8
105	97	93	90	88	84	83	83	82	82	82	82	82	8
112	104	99	96	93	89	88	87	86	86	85	85	84	8
122	113	108	104	101	97	95	94	93	92	91	90	89	8
	120	116	111	108	103	101	99	97	96	94	93	92	9
	118	113	108	104	99	96	94	92	90	88	86	85	8
	118	113	107	103	98	94	92	89	87	85	82	81	7
	115	110	104	99	94	90	87	84	81	78	76	74	7
	117	111	105	100	94	90	86	83	80	77	74	71	6
	117	111	105	99	93	89	85	81	78	74	71	58	6
	116	110	104	98	92	87	83	79	75	71	67	64	6
	118	112	105	99	93	88	83	79	74	70	66	63	5
	122	116	109	103	96	90	85	80	75	71	66	62	5
	111	105	122	115	109	102	97	91	86	81	75	71	6
	123	117	110	123	120	113	107	101	95	90	84	79	7
	122	117	120	112	106	123	116	110	104	97	91	86	7

HYDROPHONE NUMBER

NE NUMBER										HYDROPHONE NUMBER				
8	39	40	41	42	43	44	45	46	47	48	49	50	51	52
79	82	83	84	86	88	89	91	93	94	96	97	100	103	
79	81	82	83	84	85	86	88	89	90	92	93	95	97	
80	82	82	83	84	84	85	86	87	88	89	89	91	93	
82	83	83	83	84	84	84	85	85	86	86	86	87	89	
84	85	84	84	84	84	84	84	84	84	84	84	84	85	
89	89	88	87	87	86	86	85	85	84	84	83	83	84	
92	91	90	89	88	87	86	85	84	83	82	81	81	81	30.
85	84	82	81	79	78	76	75	73	72	71	70	68	68	67
81	79	77	75	73	71	69	67	66	64	62	61	59	58	57.
74	71	69	67	64	62	60	57	55	53	51	49	47	46	44
71	68	66	63	60	58	55	52	50	47	44	42	39	38	36
68	64	62	58	55	52	49	46	43	40	37	34	31	29	27
64	60	57	53	50	46	43	39	36	32	29	26	22	20	17
63	58	55	51	47	43	39	35	32	28	24	21	17	14	11
62	57	53	48	44	39	35	30	26	22	17	14	9	5	2
71	65	61	56	51	46	41	35	31	26	21	17	11	7	3
79	72	68'	62	56	51	46	39	34	29	23	19	12	8	3
86	79	73	67	61	55	49	42	36	30	24	19	12	7	2

Figure 58. Arrival Times for SSB(N) 598 Class Submarine (Sheet 3)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
1	100	115	12	29	44	60	76	91	108	1	17	33
2	100	115	11	27	42	57	72	87	103	118	11	26
3	100	114	10	26	39	54	69	83	99	113	4	20
4	101	115	9	25	38	52	66	80	95	109	0	15
5	112	1	20	34	47	60	74	87	101	115	5	19
6	119	7	25	39	52	65	78	91	105	118	7	22
7	4	16	34	47	60	72	85	98	111	0	13	27
8	7	19	36	49	61	73	86	98	111	123	12	24
9	23	35	51	63	75	87	99	111	123	11	23	37
10	32	44	59	71	82	94	105	117	5	16	28	41
11	43	54	69	80	91	102	113	0	12	23	34	47
12	54	64	79	89	100	111	122	8	19	30	41	53
13		67	81	91	101	112	122	8	19	29	39	51
14		69	83	92	102	112	122	8	18	28	38	48
15		78	91	100	110	119	4	14	23	33	42	52
16		79	91	100	109	118	3	12	21	30	39	48
17		83	96	103	112	121	5	14	22	31	40	48
18		87	99	106	115	123	7	15	23	31	40	48
19			103	109	118	1	9	17	24	32	40	48
20			113	119	3	10	18	25	32	40	47	54
21				117	1	7	14	22	28	35	42	49

2

HYDROPHONE NUMBER

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
17	33	49	64	86	101	117	10	26	43	59	52	68	85	92
11	26	42	56	78	92	108	0	16	32	48	65	78	74	91
4	20	35	49	70	84	99	114	5	21	37	53	69	86	79
0	15	29	43	63	77	91	106	121	12	27	43	59	76	93
5	19	33	46	66	79	93	107	121	11	27	42	58	74	91
7	22	35	48	67	80	93	107	121	11	26	41	57	72	89
13	27	40	53	71	84	97	110	0	13	28	42	58	73	89
12	24	38	50	68	80	93	106	119	8	22	36	52	67	83
23	37	49	61	78	90	102	11[illegible]	4	16	29	44	59	74	89
28	41	53	64	81	93	105	117	5	17	30	44	59	73	88
34	47	58	69	85	97	108	120	8	20	32	45	60	74	89
41	53	64	75	90	101	112	123	11	22	34	47	62	75	89
39	51	61	72	87	97	108	119	6	17	28	40	55	68	82
38	48	59	69	83	93	104	114	1	11	22	33	47	60	74
42	52	63	72	86	96	106	116	2	12	22	33	46	59	72
39	48	57	68	81	90	100	109	119	5	14	24	38	49	62
40	48	57	67	80	89	98	107	116	1	11	20	33	44	56
40	48	56	65	78	86	95	104	112	121	6	15	27	38	49
40	48	56	61	76	85	93	101	109	118	2	11	23	32	43
47	54	62	70	82	90	97	105	113	121	5	13	24	34	44
42	49	56	64	74	83	90	97	105	112	120	3	14	23	33

HYD

3

HYDROPHONE NUMBER

	25	26	27	28	29	30	31	32	33	34	35	36	37	38
78	92	107												
4	91	107												
66	79	95												
76	93	109												
74	91	106												
72	89	104												
73	89	105												
67	83	98												
74	89	105												
73	88	103												
74	89	104												
75	89	104												
68	82	96	119											
60	74	88	111											
59	72	86	109											
49	62	76	99											
44	56	70	93											
38	49	62	86											
32	43	56	79	95										
34	44	56	79	95										
23	33	45	66	83	100									

MBER

HYDROPHONE NUMBER

38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

Figure 59. Sampling Times for SSB(N) 598 Class Submarine (Sheet 1)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
22					2	9	15	22	28	35	41	48
23						16	22	29	34	41	47	53
24							24	30	35	41	47	53
25								33	37	43	48	54
26									38	43	48	54
27										51	56	61
28											52	57
29												69
30												
31												
32												
33												
34												
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												

2

HYDROPHONE NUMBER

12	13	14	15	16	17	18	19	20	21	22	23	24	25
48	55	62	72	79	87	94	101	108	115	122	9	17	27
53	59	66	76	83	90	97	103	110	117	123	9	17	26
53	59	65	74	81	87	94	100	107	113	119	5	12	21
54	60	66	74	81	86	92	99	105	111	117	2	9	17
54	59	65	73	79	84	90	96	102	108	113	122	4	12
61	66	72	79	85	90	95	101	107	112	117	1	7	14
57	62	67	75	80	85	90	95	100	105	110	118	0	6
69	74	79	86	91	96	100	105	109	115	119	2	7	13
	66	71	77	82	86	90	94	98	103	106	112	118	123
		85	91	95	99	103	107	111	115	117	0	4	8
		82	88	92	96	99	103	107	110	113	118	121	2
			88	93	96	100	103	107	110	113	117	120	123
				98	102	106	109	113	116	119	123	1	4
					100	104	107	111	115	117	121	0	2
						109	112	116	120	123	2	5	7
							108	112	116	119	122	1	3
								0	4	7	10	13	15
									5	8	12	15	17
										15	18	21	24
											42	45	48
												46	49
													54
													61

HYDROPH

3

HYDROPHONE NUMBER

HYDROPHONE NUMBER

25	26	27	28	29	30	31	32	33	34	35	36	37	38
27	38	59	75	93	110								
26	37	58	74	92	109	1							
21	31	51	67	84	102	119	12						
17	27	47	62	80	98	114	7	23					
12	21	41	56	73	91	108	1	17	33				
14	24	42	58	75	92	109	3	19	35	51			
6	15	33	48	66	83	99	117	9	26	42	58		
13	21	38	53	70	87	103	122	14	30	46	63	79	
123	6	22	36	53	70	85	103	120	12	29	45	61	77
8	15	29	43	59	76	91	108	1	17	34	50	66	81
2	8	21	34	50	66	80	97	113	6	22	38	54	69
123	6	18	30	45	60	74	90	106	122	14	30	46	61
4	10	21	32	46	61	74	90	105	120	12	28	43	58
2	7	18	29	42	56	68	84	96	113	4	20	35	49
7	12	22	33	45	59	71	86	100	115	5	21	36	50
3	8	16	27	40	53	64	79	93	107	121	12	27	41
15	20	29	38	50	63	74	88	102	116	6	20	35	48
17	21	30	39	50	63	73	87	100	114	3	17	32	45
24	28	36	45	56	68	78	91	104	117	6	20	34	47
48	52	59	67	77	89	98	111	0	12	25	39	52	65
49	53	59	67	77	88	97	109	121	10	22	35	48	60
54	58	64	72	81	92	100	112	0	12	24	36	49	61
61	65	71	78	87	97	105	116	4	15	27	38	51	63

4

BER HYDROPHONE NUMBER

38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
77														
81	104													
69	91													
61	82	97												
58	79	93	109											
49	70	84	99	114										
50	70	84	99	114	5									
41	61	75	89	104	118	9								
48	68	81	95	110	0	14	30							
45	64	77	91	105	119	9	24	38						
47	65	78	92	105	119	8	23	37	51					
65	83	95	108	122	11	24	39	52	65	79				
60	78	90	103	116	5	17	31	44	57	70	82			
61	78	90	102	114	3	15	28	40	54	67	78	92		
63	79	90	102	114	2	14	27	39	52	64	76	89		

Figure 59. Sampling Times for SSB(N) 598 Class Submarine (Sheet 2)

HYDROPHONE NUMBER

1 2 3 4 5 6 7 8 9 10 11 12

BEAM NUMBERC

45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62

2'

HYDROPHONE NUMBER

HYDROP

12 13 14 15 16 17 18 19 20 21 22 23 24 25

3

HYDROPHONE NUMBER

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	73	78	85	93	103	110	121	8	19	30	41	54	65	
	78	83	89	97	106	113	0	10	21	31	42	53	65	
	84	89	95	103	111	118	4	14	24	34	44	55	66	
	91	96	102	109	117	123	8.	18	27	37	47	57	68	
	98	103	108	115	122	4	13	22	31	41	50	60	70	
	108	112	117	123	6	12	20	29	38	47	56	65	75	
		119	1	6	13	18	26	34	42	51	59	68	78	
		117	122	3	9	14	21	29	37	45	53	61	70	
		117	122	2	8	13	19	27	34	42	50	57	66	
		114	119	123	4	9	15	22	29	36	43	51	59	
		116	120	0	5	9	15	21	28	35	42	49	56	
		116	120	0	4	8	14	20	26	33	39	46	53	
		115	119	123	3	7	12	18	24	30	36	42	49	
		117	121	0	4	8	13	18	24	29	35	41	48	
		121	1	4	8	11	15	20	25	30	36	41	47	
		109	114	17	20	24	27	32	36	41	46	50	56	
		122	2	5	28	35	38	42	46	50	55	59	64	
		121	2	15	17	21	48	51	55	59	62	66	71	

HYDROPHONE NUMBER

HYDROPHONE NUMBER

38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
65	81	92	103	115	3	14	26	38	49	62	73	86	102	
65	80	91	102	113	0	11	23	34	45	58	69	81	96	
66	81	91	102	113	123	10	21	32	43	54	65	77	92	
68	82	92	102	113	123	9	20	30	41	51	61	73	88	
70	84	93	103	113	123	9	19	29	39	49	59	70	84	
75	88	97	106	116	1	11	20	30	39	49	58	68	83	
78	90	99	108	117	2	11	20	29	38	47	56	66	80	89
70	83	91	100	108.	117	1	10	18	27	36	45	53	66	75
66	77	86	94	102	110	118	2	11	19	27	36	44	56	65
59	69	77	85	93	101	109	116	0	8	16	24	32	44	52
56	66	74	81	88	97	104	111	119	2	9	17	24	36	44
53	62	70	76	83	90	98	105	112	119	2	9	16	27	35
49	58	65	71	78	84	91	97	105	111	118	1	7	18	25
48	56	63	69	75	81	87	93	100	107	113	120	2	12	19
47	55	61	66	72	77	83	88	94	100	105	113	118	3	10
56	63	69	74	79	84	89	93	99	104	109	116	120	5	11
64	70	76	80	84	89	94	97	102	107	111	118	121	6	11
71	77	81	85	89	93	97	100	104	108	112	117	121	5	10

Figure 59. Sampling Times for SSB(N) 598 Class Submarine (Sheet 3)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
1	0	6	13	18	25	31	37	42	49	55	61	67
2	1	7	13	17	24	29	34	39	45	51	56	62
3	0	5	10	14	20	24	29	33	39	44	49	54
4	1	5	10	14	19	23	27	31	36	40	44	49
5	11	15	19	22	26	30	33	36	41	44	48	52
6	20	23	27	29	33	36	39	42	46	49	53	56
7	27	29	33	35	38	41	44	46	50	53	56	59
8	36	38	41	43	46	48	51	53	56	58	61	64
9	47	49	52	53	56	58	60	61	64	66	68	70
10	55	56	59	60	62	63	65	66	68	70	71	73
11	65	66	68	69	70	71	72	73	75	76	77	79
12	75	76	77	77	78	79	80	80	81	82	83	84
13		80	81	81	81	81	82	82	82	83	83	84
14		81	82	81	81	81	81	80	80	80	80	80
15		82	82	81	80	80	79	78	78	77	77	76
16		88	88	86	85	84	83	82	81	80	79	78
17		91	91	89	87	86	84	83	81	80	78	77
18		95	94	92	90	88	86	84	82	80	78	76
19			96	94	91	89	86	84	82	79	77	75
20			102	99	96	93	90	88	85	82	79	77
21				101	97	94	91	88	84	81	78	75

2

HYDROPHONE NUMBER

12	13	14	15	16	17	18	19	20	21	22	23	24	25
67	73	80	86	94	99	106	112	118	122	107	113	119	115
62	67	73	79	87	91	97	103	109	115	122	103	110	116
54	59	64	69	76	80	86	91	97	103	109	115	121	103
49	53	58	63	69	73	78	83	88	94	99	105	111	117
52	56	60	64	70	73	78	82	87	92	97	102	108	114
56	60	63	67	73	76	80	84	89	93	98	103	109	115
59	62	65	69	74	76	80	84	88	92	97	102	107	113
64	66	69	73	77	79	83	86	90	94	98	103	108	113
70	73	75	78	82	84	87	90	93	97	101	105	110	115
73	75	77	80	83	85	87	90	93	96	100	104	108	113
79	80	82	84	87	88	90	93	95	98	101	105	109	114
84	85	86	88	90	91	93	95	97	99	102	105	109	113
84	84	85	87	88	89	90	91	93	95	97	100	104	108
80	80	81	82	83	83	84	85	86	88	90	92	95	99
76	76	76	77	77	77	77	78	79	80	81	83	86	89
78	77	76	77	77	76	76	76	77	77	78	80	82	85
77	76	75	75	74	73	72	72	72	72	73	74	76	78
76	75	73	73	71	70	69	68	68	68	68	68	70	72
75	73	71	70	68	66	65	64	63	62	62	62	63	65
77	74	72	71	68	66	64	63	61	60	59	59	60	61
75	72	69	68	65	62	60	58	56	55	53	53	53	54

HYDROPH

3

HYDROPHONE NUMBER

HYDROPHONE NUMBER

5	26	27	28	29	30	31	32	33	34	35	36	37	38	39
115	120													
116	112													
103	110													
117	122													
114	121													
115	121													
113	119													
113	120													
115	121													
113	119													
114	119													
113	119													
108	113	120												
99	104	111												
89	94	101												
85	89	96												
78	82	89												
72	75	82												
65	68	74	81											
61	64	70	76											
54	56	62	68	75										

4

HYDROPHONE NUMBER

NUMBER

38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

Figure 60. Arrival Times for SSB(N) 608 Class Submarine (Sheet 1)

BEAM NUMBER	HYDROPHONE NUMBER 1	2	3	4	5	6	7	8	9	10	11	12
22					99	95	92	89	85	81	78	74
23						99	95	91	87	83	79	75
24							103	99	94	90	86	81
25								93	88	83	79	74
26									90	85	80	75
27										91	86	81
28											80	75
29												84
30												
31												
32												
33												
34												
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												

2

HYDROPHONE NUMBER

HYDR

1	12	13	14	15	16	17	18	19	20	21	22	23	24	25
78	74	71	68	66	62	60	57	54	52	50	48	47	47	47
79	75	72	68	66	62	59	56	53	50	48	45	44	43	43
86	81	77	73	71	66	63	59	56	53	50	47	46	44	44
79	74	70	65	63	57	54	50	46	43	40	36	34	33	32
80	75	70	66	63	57	53	49	45	41	37	34	31	29	28
86	81	76	71	68	61	57	53	48	44	40	36	33	31	29
80	75	70	64	61	54	50	45	40	36	31	27	24	21	18
	84	78	73	69	62	57	52	47	42	37	32	28	25	22
		82	76	72	64	59	53	48	42	37	31	27	23	19
			80	76	67	62	56	50	44	38	32	27	22	18
			82	78	69	64	58	51	45	39	32	27	21	16
				84	75	70	64	57	51	44	37	32	26	20
					81	76	70	63	57	50	43	37	31	25
						85	79	72	66	59	52	46	40	34
							79	73	66	60	53	47	40	34
								74	68	62	55	49	42	36
									73	67	60	54	47	41
										76	70	64	57	50
											73	67	61	54
												65	59	52
													82	75
														73
														82

3

HYDROPHONE NUMBER

HYDROPHONE NUMBER

24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
47	47	49	55	61	68	74								
43	43	44	50	56	63	69	75							
44	44	45	50	56	63	69	75	81						
33	32	32	37	43	49	56	62	68	74					
29	28	28	32	38	44	51	57	63	70	76				
31	29	28	32	38	44	51	57	63	70	76	82			
21	18	18	21	27	33	39	45	52	58	65	71	77		
25	22	20	23	28	34	40	46	53	59	66	72	78	83	
23	19	16	19	23	29	34	40	47	53	59	66	72	77	86
22	18	15	16	20	25	30	35	42	48	54	60	66	71	80
21	16	12	13	16	20	25	30	36	41	47	53	59	64	72
26	20	15	15	17	21	25	29	35	40	45	51	56	61	69
31	25	20	18	20	23	26	30	34	39	44	49	54	58	66
40	34	28	26	27	29	32	35	39	43	48	52	57	61	64
40	34	28	26	26	28	30	33	37	41	45	49	53	57	63
42	36	30	27	27	28	30	32	36	39	43	47	51	54	60
47	41	35	31	31	32	33	35	38	41	45	48	52	55	61
57	50	44	41	40	40	41	43	45	48	51	54	57	60	65
61	54	48	44	42	42	43	44	46	48	51	54	57	59	64
59	52	46	42	40	39	39	40	42	44	46	48	51	53	57
82	75	69	64	62	61	61	61	62	64	65	67	69	71	75
	73	67	62	59	58	57	57	58	59	60	61	63	65	66
	82	75	70	67	65	64	63	64	64	65	66	67	69	71

NUMBER	HYDROPHONE NUMBER														
	38	39	40	41	42	43	44	45	46	47	48	49	50	51	5
3															
77	86														
71	80	86													
64	72	78													
61	69	75	81												
58	66	71	77	82											
61	68	73	78	83	88										
57	63	68	73	78	83	88									
54	60	65	69	74	79	83	88								
55	61	65	69	73	78	82	86	92							
60	65	69	73	77	81	85	89	94	97						
59	64	67	71	74	78	82	85	90	93	97					
53	57	60	63	66	70	73	76	80	83	87	90				
71	75	78	80	83	86	89	92	95	98	101	104	107			
65	68	70	73	75	77	80	82	85	88	90	93	96	99		
69	71	73	75	77	79	81	83	86	88	90	92	95	97		

Figure 60. Arrival Times for SSB(N) 608 Class Submarine (Sheet 2)

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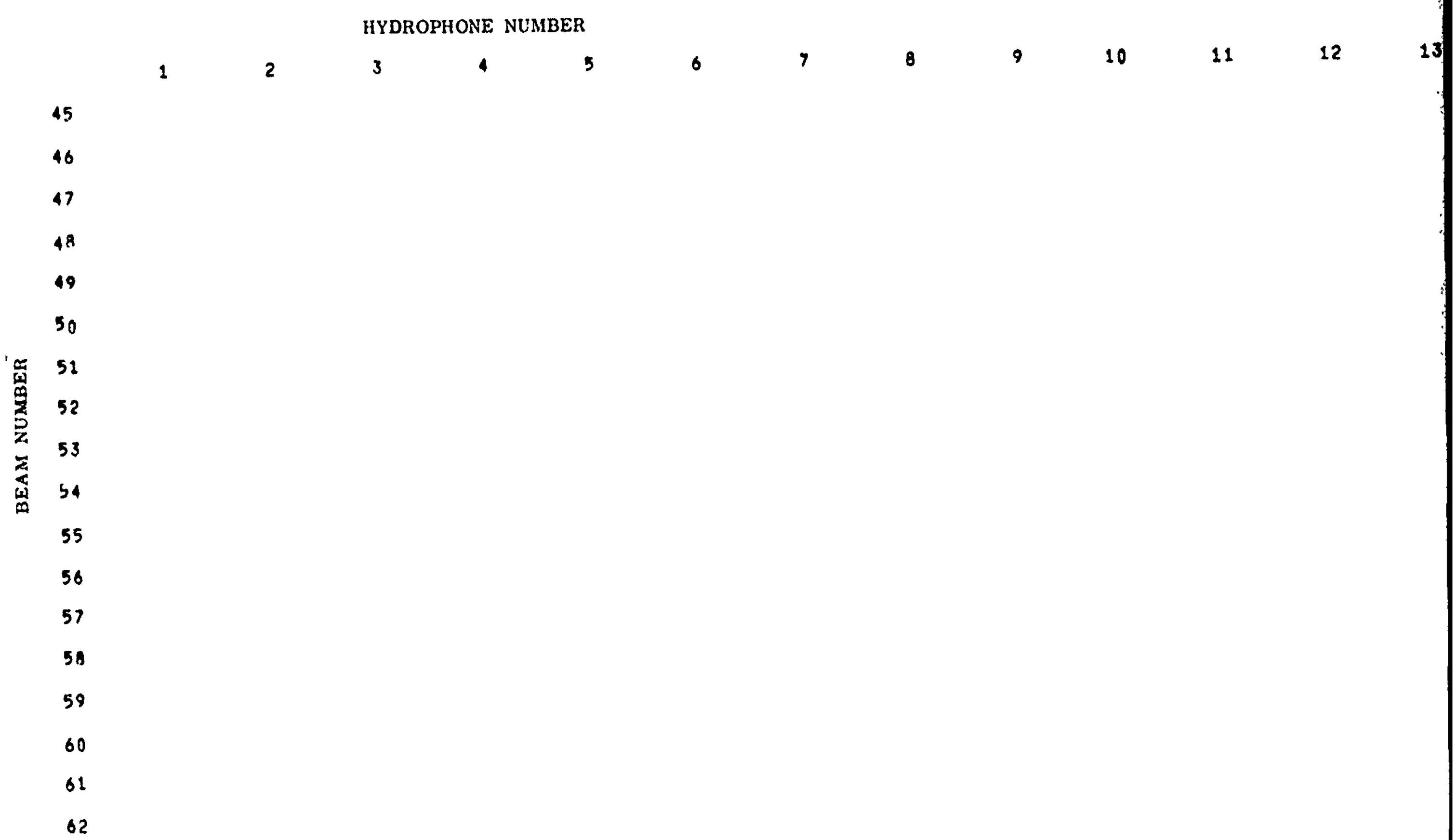

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2

HYD

HYDROPHONE NUMBER

1 12 13 14 15 16 17 18 19 20 21 22 23 24 25

3

HYDROPHONE NUMBER

HYDROPHONE NUMBER

25	26	27	28	29	30	31	32	33	34	35	36	37	38
	82	77	73	71	69	68	68	68	68	69	70	71	7
	88	83	79	76	74	73	72	72	72	72	72	73	7
	96	91	86	83	81	79	78	77	76	76	76	76	7
	104	99	94	91	88	86	84	83	82	81	80	80	8
	109	103	98	94	91	88	86	85	83	82	81	81	8
	118	112	107	103	99	96	94	92	90	88	87	86	8
		117	112	107	103	100	97	94	92	90	88	87	8
		122	116	111	107	103	100	97	94	92	89	88	8
		122	116	111	106	102	98	95	92	89	86	84	8
		118	112	107	101	97	93	89	86	82	79	77	7
		120	114	108	103	98	94	90	86	82	79	76	7
		120	114	108	102	97	93	88	84	80	76	73	6
		119	112	106	100	95	90	85	80	76	72	69	6
		120	114	108	102	96	91	86	81	76	71	68	[illegible]
		105	122	116	110	104	98	93	87	82	77	73	6
		111	105	122	116	110	104	98	92	86	81	76	6
		115	119	113	106	124	117	111	105	99	93	88	[illegible]
		123	117	121	115	109	123	120	113	107	100	95	[illegible]

HYDROPHONE NUMBER

MBER	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
	72	74	76	77	79	80	82	84	86	87	89	91	93	96	
	74	75	76	77	79	83	81	82	84	85	87	88	90	92	
	77	78	78	79	80	80	81	82	83	84	85	86	87	89	
	80	81	81	81	81	82	82	82	83	83	84	84	85	87	
	80	80	80	79	79	79	79	79	79	79	79	79	79	81	
	84	84	84	83	82	82	81	80	80	80	79	79	79	80	
	85	84	83	82	81	80	79	78	77	76	75	74	74	74	
	85	84	83	81	80	78	77	75	74	73	71	70	69	69	
	81	80	78	76	74	72	70	68	66	65	63	61	60	59	
	73	72	69	67	64	62	60	57	55	53	51	48	47	46	
	72	70	67	64	61	58	56	53	50	48	45	42	40	39	
	68	66	63	59	56	53	50	46	44	41	38	34	32	30	
	63	61	57	53	50	46	43	39	36	32	29	25	22	20	
	62	59	55	51	47	43	39	35	32	28	24	20	17	14	
	66	63	58	54	49	45	40	35	31	27	22	17	14	11	
	69	65	60	55	50	45	40	34	30	25	20	14	10	6	
	80	76	70	64	59	53	47	41	36	31	25	19	14	10	
	86	82	76	69	63	57	51	43	38	32	26	19	13	8	

Figure 60. Arrival Times for SSB(N) 608 Clas Submarine (Sheet 3)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
1	100	116	13	28	45	61	77	92	109	2	18	34
2	101	117	13	27	44	59	74	89	105	121	13	29
3	100	115	10	24	40	54	69	83	99	114	5	21
4	101	115	9	24	39	53	67	81	96	110	0	16
5	111	1	19	32	46	60	73	86	101	114	4	19
6	120	9	27	39	53	66	79	92	106	119	9	23
7	3	15	33	45	58	71	84	96	110	123	12	26
8	12	24	41	53	66	78	91	103	116	4	17	31
9	23	36	52	63	76	88	100	111	0	12	24	37
10	31	43	59	70	82	93	105	116	4	16	27	40
11	42	53	68	79	90	101	112	123	11	22	33	46
12	52	63	77	87	98	109	120	6	17	28	39	51
13		67	81	91	101	111	122	8	18	29	39	51
14		68	82	91	101	111	121	6	16	26	36	46
15		69	82	91	100	110	119	4	14	23	33	42
16		75	88	96	105	114	123	8	17	26	35	44
17		78	91	99	107	116	0	9	17	26	34	43
18		82	94	102	110	118	2	10	18	26	34	42
19			96	104	111	119	2	10	18	25	33	41
20			102	109	116	123	6	14	21	28	35	43
21				111	117	0	7	14	20	27	34	41

2

HYDROPHONE NUMBER

HYDROPH

12	13	14	15	16	17	18	19	20	21	22	23	24	25
34	50	67	86	104	119	13	29	45	59	54	70	86	92
29	44	60	79	97	111	4	20	36	52	69	60	77	93
21	36	51	69	86	100	116	8	24	40	56	72	88	80
16	30	45	63	79	93	108	123	15	31	46	62	78	94
19	35	47	64	80	93	108	122	13	29	44	59	75	91
23	37	50	67	83	96	110	0	15	30	45	60	76	92
26	39	52	69	84	96	110	0	14	29	44	59	74	90
31	43	56	73	87	99	113	2	16	31	45	60	75	90
37	50	62	78	92	104	117	6	19	34	48	62	77	92
40	52	64	80	93	105	117	6	19	32	47	61	75	90
46	57	69	84	97	108	120	9	21	34	48	62	76	91
51	62	73	88	100	111	123	11	23	35	49	62	76	90
51	61	72	87	98	109	120	7	19	31	43	57	71	85
46	57	68	82	93	103	114	1	12	24	36	48	62	76
42	52	63	77	87	97	107	118	5	16	27	39	52	66
44	53	63	77	87	96	106	116	3	13	24	36	48	62
43	52	61	75	84	93	102	112	122	8	19	30	42	54
42	51	59	73	81	90	99	108	118	4	14	24	36	48
41	49	57	69	78	86	95	104	113	122	8	18	29	41
43	50	58	70	78	86	94	103	111	120	5	15	26	37
41	48	55	67	74	82	90	98	106	115	123	9	19	30

3

HYDROPHONE NUMBER

HYDROPHONE NUMBER

	25	26	27	28	29	30	31	32	33	34	35	36	37	38
86	92	107												
77	93	99												
88	80	97												
78	94	109												
75	91	108												
76	92	108												
74	90	106												
75	90	107												
77	92	108												
75	90	106												
76	91	106												
76	90	106												
71	85	100	120											
62	76	91	111											
52	66	81	101											
48	62	76	96											
42	54	69	89											
36	48	61	82											
29	41	54	74	91										
26	37	50	69	86										
19	30	42	61	77	95									

4

UMBER

HYDROPHONE NUMBER

38	39	40	41	42	43	44	45	46	47	48	49	50	51	52

Figure 61. Sampling Times for SSB(N) 608 Class Submarine (Sheet 1)

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HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
22					119	1	8	15	21	27	34	4[illegible]
23						5	11	17	23	29	35	4[illegible]
24							19	25	30	36	42	4[illegible]
25								19	24	29	35	4[illegible]
26									26	31	36	4[illegible]
27										37	42	4[illegible]
28											36	4[illegible]
29												5[illegible]
30												
31												
32												
33												
34												
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												

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2

HYDROPHONE NUMBER

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
34	40	47	54	65	71	79	87	94	102	110	118	3	13	[illegible]
35	41	48	54	65	71	78	85	93	100	108	115	0	9	[illegible]
42	47	53	59	70	75	82	88	96	103	[illegible]	117	2	10	[illegible]
35	40	46	51	62	66	73	79	85	92	100	106	114	123	
36	41	46	52	62	66	72	78	84	90	96	104	111	119	
42	47	52	57	67	70	76	82	87	93	99	106	113	121	
36	41	46	50	60	63	69	74	79	85	90	96	103	111	[illegible]
	50	54	59	68	71	76	81	86	91	96	101	107	115	[illegible]
		58	62	71	73	78	82	87	91	96	100	106	112	[illegible]
			66	75	76	81	85	89	93	97	101	106	111	[illegible]
			68	77	78	83	87	90	94	98	101	106	110	[illegible]
				83	84	89	93	96	100	103	106	111	115	[illegible]
					90	95	99	102	106	109	112	116	120	
						104	108	111	115	118	121	1	5	
							108	112	115	119	122	2	5	
								113	117	121	0	4	7	
									122	2	5	9	12	
										11	15	19	22	
											18	22	26	
												20	24	
													48	

3

HYDROPHONE NUMBER

HYDROPHONE NUM

	24	25	26	27	28	29	30	31	32	33	34	35	36	37
3	13	23	35	54	70	88	104							
0	9	19	30	49	65	82	99	115						
2	10	20	31	49	65	82	99	115	7					
114	123	8	18	36	52	68	85	102	118	10				
111	119	4	14	31	47	63	80	96	113	6	22			
113	121	5	14	31	47	63	80	96	113	6	22	38		
103	111	118	4	20	36	52	68	84	101	118	11	27	43	
107	115	122	6	22	37	53	69	85	102	119	12	28	44	59
105	112	119	2	18	32	48	63	79	96	112	5	22	38	53
106	111	117	1	15	29	44	59	74	91	107	0	16	32	47
106	110	115	121	12	25	39	54	69	85	100	116	9	25	40
111	115	119	0	14	26	40	54	68	84	99	114	7	22	37
116	120	0	5	17	29	42	55	69	83	98	113	4	20	34
1	5	9	14	25	36	48	61	74	88	102	117	7	23	37
2	5	9	13	25	35	47	59	72	86	100	114	4	19	33
4	7	11	15	26	36	47	59	71	85	98	112	2	16	30
9	12	16	20	30	40	51	62	74	87	100	114	3	17	31
19	22	25	30	40	49	59	70	82	94	107	120	9	22	36
22	26	29	34	43	51	61	72	83	95	107	120	9	22	35
20	24	27	31	41	49	58	68	79	91	103	115	3	16	28
	48	51	55	63	71	80	90	100	111	123	10	22	34	47
		49	53	61	68	77	86	96	107	118	5	16	28	40
		58	61	69	76	84	93	102	113	123	10	21	32	44

4

HYDROPHONE NUMBER

36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
43														
44	59													
38	53	72												
32	47	66	85											
25	40	58	77											
22	37	55	74	90										
20	34	52	70	86	101									
23	37	54	72	87	102	117								
19	33	49	67	82	97	112	3							
16	30	46	64	78	93	108	122	13						
17	31	47	64	78	92	107	121	11	28					
22	36	51	68	82	96	110	0	14	30	43				
22	35	50	66	80	93	107	121	10	25	39	53			
16	28	43	59	72	85	99	112	1	15	28	43	56		
34	47	61	77	89	102	115	4	17	30	44	57	70	83	
28	40	54	69	82	94	106	119	7	20	33	46	59	72	
32	44	57	72	84	96	108	120	8	21	33	45	58	71	

HYDROPHON

Figure 61. Sampling Times for
Submarine (Sheet 2)

5

HYDROPHONE NUMBER

45	46	47	48	49	50	51	52
3							
1	28						
4	30	43					
0	25	39	53				
1	15	28	43	56			
17	30	44	57	70	83		
7	20	33	46	59	72	85	
8	21	33	45	58	71	83	

Figure 61. Sampling Times for SSB(N) 608 Class Submarine (Sheet 2)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11
45											
46											
47											
48											
49											
50											
51											
52											
53											
54											
55											
56											
57											
58											
59											
60											
61											
62											

2

HYDROPHONE NUMBER

10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

3

HYDROPHONE NUMBER

HYDROPHONE

23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
			68	76	82	90	98	107	117	3	13	24	35	
			74	82	88	95	103	112	121	7	17	27	37	
			82	90	95	102	110	118	3	12	21	31	41	
			90	98	103	110	117	1	9	18	27	36	45	
			95	102	107	113	120	3	11	20	28	37	46	
			104	111	116	122	4	11	19	27	35	43	52	
				116	121	2	8	15	22	29	37	45	53	
				121	1	6	12	18	25	32	39	47	54	
				121	1	6	11	17	23	30	37	44	51	
				117	121	2	6	12	18	24	31	37	44	
				119	123	3	8	13	19	25	31	37	44	
				119	123	3	7	12	18	23	29	35	41	
				118	121	1	5	10	15	20	25	31	37	
				119	123	3	7	11	16	21	26	31	36	
				103	7	11	15	19	23	28	32	37	42	
				109	114	17	21	25	29	33	37	41	46	
				113	4	8	11	39	42	46	50	54	58	
				122	2	16	20	24	48	55	58	62	65	

HYDROPHONE NUMBER

36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
35	46	58	73	85	96	108	119	7	19	31	42	55	67	[illegible]
37	48	60	74	85	96	108	119	6	17	29	40	52	64	[illegible]
41	51	63	77	87	98	109	119	6	17	28	39	50	62	[illegible]
45	55	66	80	90	100	110	121	7	17	28	38	49	59	[illegible]
46	56	65	79	89	98	108	118	4	14	24	34	44	54	[illegible]
52	61	69	83	93	102	111	121	6	15	25	35	44	54	[illegible]
53	62	70	83	92	101	110	119	4	13	22	31	40	49	[illegible]
54	63	70	83	92	100	109	117	2	10	19	28	36	45	[illegible]
51	59	66	78	87	95	103	111	119	3	11	20	28	36	[illegible]
44	52	58	70	77	85	93	101	109	116	0	8	16	23	[illegible]
44	51	57	68	75	82	89	97	105	112	119	3	10	17	[illegible]
41	48	53	64	71	77	84	91	99	105	113	120	3	9	
37	44	48	59	65	71	78	84	91	97	105	111	118	0	
36	43	47	57	63	69	75	81	87	93	100	107	113	119	
42	48	51	61	66	72	77	83	88	93	99	105	111	116	[illegible]
46	51	54	63	68	73	78	83	88	92	98	103	108	113	[illegible]
58	63	65	74	78	82	87	91	95	99	104	109	113	118	[illegible]
65	70	71	80	84	87	91	95	99	101	106	110	114	117	[illegible]

HYDROPHONE

Figure 61. Sampling Times for
Submarine (Sheet 3)

S

HYDROPHONE NUMBER

45	46	47	48	49	50	51	52
19	31	42	55	67	79	95	
17	29	40	52	64	76	91	
17	28	39	50	62	73	88	
17	28	38	49	59	71	86	
14	24	34	44	54	64	80	
15	25	35	44	54	64	79	
13	22	31	40	49	59	72	83
10	19	28	36	45	54	67	76
3	11	20	28	36	45	57	66
116	0	8	16	23	32	44	52
112	119	3	10	17	25	37	44
105	113	120	3	9	17	28	35
97	105	111	118	0	7	18	25
93	100	107	113	119	2	12	19
93	99	105	111	116	123	9	14
92	98	103	108	113	119	4	10
99	104	109	113	118	123	8	12
101	106	110	114	117	122	6	10

Figure 61. Sampling Times for SSB(N) 608 Class Submarine (Sheet 3)

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HYDROPHONE NUMBER

BEAM NUMBER

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	6	13	19	25	31	37	42	49	55	61	67
2	1	5	12	17	22	28	33	38	44	49	55	60
3	1	5	11	15	20	25	30	34	39	44	49	54
4	1	4	9	13	17	22	26	29	34	39	43	47
5	12	15	20	23	27	30	34	37	41	45	49	52
6	20	23	27	30	33	36	39	42	46	49	53	56
7	28	30	34	35	39	42	45	47	51	54	57	60
8	32	32	35	37	40	42	45	47	50	52	55	57
9	45	47	49	51	53	55	57	59	61	63	66	68
10	56	57	60	61	63	54	66	67	69	71	73	74
11	60	67	69	69	71	72	73	74	75	77	78	79
12	75	76	77	79	78	79	80	80	81	82	83	84
13		80	91	81	81	92	82	82	82	83	83	84
14		83	83	83	83	92	82	82	82	82	82	82
15		81	81	80	80	79	78	78	77	77	76	7[illegible]
16		91	91	89	88	87	86	85	84	83	82	81
17		91	91	89	87	86	84	83	81	80	79	7[illegible]
18		95	94	91	90	88	86	84	82	80	78	7[illegible]
19			103	100	98	96	93	91	88	86	84	8[illegible]
20			102	98	96	93	90	88	85	82	79	7[illegible]
21				100	98	94	91	88	85	82	79	7[illegible]

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2

HYDROPHONE NUMBER

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
61	67	73	79	86	93	99	105	111	117	122	107	113	119	[illegible]
55	60	56	71	78	84	89	95	101	107	113	119	101	108	[illegible]
49	54	59	63	70	76	80	85	91	96	102	108	114	121	[illegible]
43	47	52	56	62	67	71	76	81	86	91	97	103	109	[illegible]
49	52	56	60	65	70	73	78	82	86	91	96	102	108	[illegible]
53	56	[illegible]	63	69	72	75	79	83	87	92	97	102	108	[illegible]
57	60	53	66	70	74	77	80	84	88	92	96	102	107	[illegible]
55	57	50	63	67	70	73	76	79	83	86	90	95	100	[illegible]
66	68	70	72	76	79	81	84	87	90	93	97	102	106	[illegible]
73	74	76	78	81	84	86	88	90	93	96	99	104	108	[illegible]
78	79	81	82	85	87	88	90	92	95	97	100	104	108	[illegible]
83	84	85	86	88	90	91	92	94	96	98	100	104	108	[illegible]
83	84	84	85	87	88	88	89	91	92	94	96	99	102	[illegible]
82	82	82	82	84	84	84	95	86	87	88	89	92	95	
76	76	75	75	76	76	76	76	76	77	78	79	81	84	
82	81	80	80	80	80	79	79	79	79	79	79	82	84	
79	77	76	75	75	74	73	72	72	71	71	71	73	74	
78	76	75	73	73	71	70	69	65	67	66	66	67	68	
84	82	80	78	77	75	73	72	70	69	68	67	68	68	
79	77	74	72	71	68	66	64	62	60	59	57	58	58	
79	76.	73	70	69	65	63	60	53	56	54	52	52	52	

3

HYDROPHONE NUMBER

24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
119	115	121												
108	115	121												
121	103	109												
109	116	122												
108	114	120												
108	114	120												
107	113	119												
100	106	112												
106	112	117												
108	113	119												
108	113	118												
108	112	117												
102	106	111	120											
95	99	103	112											
84	87	91	100											
84	86	90	99											
74	77	80	89											
68	70	73	81											
68	70	72	80	86										
58	59	61	69	75										
52	52	54	61	67	74									

HYDROPHONE NUMBER

4

HYDROPHONE NUMBER

E NUMBER

38 39 40 41 42 43 44 45 46 47 48 49 50 51

Figure 62. Arrival Times for Compromise Be
former Between the SSB(N) 598 ar
SSB(N) 608 Class Submarines (Shee

BEAM NUMBER	HYDROPHONE NUMBER 1	2	3	4	5	6	7	8	9	10	11	12
22					100	97	93	90	86	83	79	76
23						99	95	92	87	84	80	76
24							103	99	94	90	86	82
25								94	89	84	80	75
26									90	86	81	76
27										86	81	76
28											83	77
29												87
30												
31												
32												
33												
34												
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												

HYDROPHONE NUMBER

	12	13	14	15	16	17	18	19	20	21	22	23	24	25
79	76	73	70	67	64	61	58	55	53	50	48	48	47	47
80	76	72	69	66	62	59	56	53	50	47	44	43	42	41
86	82	78	74	71	67	63	60	56	53	50	46	45	43	42
80	75	71	67	65	59	55	51	47	43	40	36	34	32	30
81	76	71	67	63	53	54	49	45	41	37	33	31	28	26
81	76	71	66	62	55	52	47	43	38	34	29	27	24	21
83	77	72	67	63	57	52	47	42	38	33	28	25	22	19
	87	81	76	71	63	60	54	49	44	39	33	30	26	22
		83	77	72	65	60	54	48	43	37	31	27	22	18
			80	74	67	62	55	49	43	37	31	26	20	15
			83	77	70	64	58	51	45	39	32	27	21	15
				84	72	71	65	58	52	45	38	33	26	20
					82	76	59	63	56	50	43	37	30	23
						81	75	68	62	55	46	42	35	23
							80	74	68	61	54	48	41	34
								74	68	62	55	48	41	34
									73	67	60	54	47	40
										77	70	64	57	50
											74	68	61	54
												66	59	52
													80	73
														73
														81

HYD

3

	HYDROPHONE NUMBER													HYDROPHONE NUMBER
	25	26	27	28	29	30	31	32	33	34	35	36	37	38
47	47	48	55	61	68	75								
42	41	42	49	55	62	69	75							
43	42	43	49	55	62	69	75	81						
32	30	31	36	42	49	56	62	69	75					
28	26	26	31	37	44	51	57	64	70	76				
24	21	21	26	31	38	45	51	58	64	70	76			
22	12	18	22	27	34	41	47	54	60	66	73	79		
26	22	20	24	29	36	42	48	55	61	68	74	80	86	
22	13	15	18	22	28	35	40	47	53	60	66	72	78	85
20	15	12	13	17	23	29	34	41	47	53	59	65	71	78
21	15	11	11	14	19	25	29	36	41	47	53	59	65	72
26	20	15	14	17	21	26	30	36	41	47	52	58	63	70
30	23	18	16	18	21	25	29	34	39	44	49	54	59	65
35	23	23	20	21	24	27	30	35	39	44	48	53	58	63
41	34	28	25	26	28	31	33	38	42	46	51	55	59	65
41	34	28	25	25	27	29	31	35	39	43	47	51	55	60
47	40	34	30	29	31	33	34	38	41	45	49	53	56	61
57	50	44	39	38	39	41	42	45	48	51	55	58	62	66
61	54	48	43	42	42	43	44	47	49	52	55	58	61	65
59	52	46	41	39	39	40	40	42	44	47	49	52	55	58
80	73	67	61	59	58	59	58	60	62	64	66	68	71	73
	73	66	60	58	57	57	56	57	59	60	62	64	66	68
	81	74	68	65	64	63	62	63	64	65	66	67	69	71

4

NUMBER	38	39	40	41	42	43	44	45	46	47	48	49	50	51	5
8	85														
1	78	86													
5	72	79													
3	70	77	82												
9	65	72	77	82											
8	63	70	74	79	85										
9	65	71	75	80	85	90									
5	60	66	70	74	79	84	88								
6	61	66	70	74	78	83	87	92							
2	66	71	74	78	82	86	90	95	98						
1	65	69	73	76	80	83	87	91	95	98					
5	58	62	65	68	71	75	78	82	85	88	92				
71	73	77	80	82	85	88	91	94	97	100	103	106			
66	68	71	73	76	78	81	83	86	88	91	94	[illegible]	[illegible]		
69	71	74	75	77	79	81	83	86	88	90	92	94	[illegible]		

HYDROPHONE NUMBER

Figure 62. Arrival Times for Compromise Beamformer Between the SSB(N) 598 and SSB(N) 608 Class Submarines (Sheet 2)

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
45												
46												
47												
48												
49												
50												
51												
52												
53												
54												
55												
56												
57												
58												
59												
60												
61												
62												

2

HYDROPHONE NUMBER

HYDRO

12 13 14 15 16 17 18 19 20 21 22 23 24 25

HYDROPHONE NUMBER

25	26	27	28	29	30	31	32	33	34	35	36	37	38
	81	74	71	69	68	66	67	67	68	69	70	71	72
	88	81	77	75	73	71	71	71	71	72	72	73	74
	97	90	86	83	81	78	78	77	77	77	77	77	78
	105	98	94	90	98	85	84	83	82	82	81	81	81
	106	99	94	91	88	84	83	81	80	79	79	78	78
	116	109	104	100	97	93	91	89	87	86	85	84	83
		116	111	107	103	99	96	94	92	90	89	87	86
		120	115	110	106	101	98	96	93	91	89	87	85
		120	115	110	105	100	97	94	91	88	86	84	81
		117	111	105	100	95	92	88	85	82	79	77	74
		117	111	105	100	95	91	87	83	80	77	74	70
		120	114	108	102	97	92	88	84	80	77	73	70
		118	112	105	100	94	89	84	80	75	72	68	64
		120	114	107	101	95	90	85	81	76	72	68	63
		124	120	113	106	100	94	89	84	79	74	70	64
		111	105	122	115	109	103	97	91	86	80	76	70
		124	118	111	104	122	115	109	103	97	91	86	79
		122	117	121	114	108	123	118	112	105	99	93	86

HYDROPHONE NUMBER

MBER														
38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
72	75	76	77	79	81	82	84	86	88	89	91	93	96	
74	76	77	78	79	80	81	83	84	85	87	[illegible]	90	92	
78	79	80	80	81	82	83	84	84	85	86	87	88	90	
81	82	82	82	83	83	83	84	84	85	85	85	86	88	
78	78	78	77	77	77	77	77	77	77	77	77	77	79	
83	83	82	81	81	80	80	79	79	78	78	77	77	79	
86	85	84	83	82	81	80	79	78	77	76	75	75	75	74
85	84	83	81	80	78	77	75	74	73	71	71	69	69	[illegible]
81	80	78	76	74	72	70	68	67	65	63	61	60	59	[illegible]
74	72	69	67	64	62	60	57	55	53	51	49	[illegible]	46	[illegible]
70	68	65	62	60	57	54	51	49	46	44	41	[illegible]	37	[illegible]
70	67	64	60	57	54	51	47	45	42	39	[illegible]	33	31	[illegible]
64	61	58	54	50	47	43	39	36	33	30	[illegible]	23	21	[illegible]
63	60	56	52	48	44	40	36	33	29	25	21	18	15	[illegible]
64	60	56	51	47	42	38	33	29	24	20	[illegible]	11	[illegible]	
70	65	60	55	50	45	40	34	30	25	20	[illegible]	10	7	
79	74	69	63	58	52	46	40	35	30	24	[illegible]	13	[illegible]	
86	80	75	68	62	55	50	43	37	31	25	[illegible]	13	[illegible]	

Figure 62. Arrival Times for Compromise Bean former Between the SSB(N) 598 and SSB(N) 608 Class Submarines (Sheet

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HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
1	100	116	13	29	45	61	77	92	109	2	18	34
2	101	115	12	27	42	58	73	88	104	119	12	27
3	101	115	11	25	40	55	70	84	99	114	5	21
4	100	114	8	23	37	52	66	79	94	109	123	14
5	112	1	20	33	47	60	74	37	101	115	5	19
6	120	9	27	40	53	66	79	92	106	119	9	23
7	4	16	34	46	59	72	85	97	111	0	13	27
8	6	18	35	47	50	72	85	97	110	122	11	23
9	21	34	49	61	73	85	97	109	121	9	22	35
10	32	44	60	71	83	94	106	117	5	17	29	41
11	43	54	69	79	91	102	113	0	11	23	34	46
12	52	63	77	88	98	109	120	6	17	28	39	51
13		67	81	91	101	112	122	8	18	29	39	51
14		70	83	93	103	112	122	8	18	28	38	4[illegible]
15		68	81	90	100	109	118	4	13	23	32	42
16		78	91	99	108	117	2	11	20	29	38	47
17		78	91	99	107	116	0	9	17	26	35	43
18		82	94	101	110	118	2	10	18	26	34	42
19			103	110	118	2	9	17	24	32	40	4[illegible]
20			102	108	116	123	6	14	21	28	35	43
21				110	118	0	7	14	21	28	35	42

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HYDROPHONE NUMBER

HYD

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
18	34	50	66	86	103	119	12	28	44	59	54	70	86	92
12	27	43	58	78	94	109	1	18	34	50	66	58	75	92
5	21	36	50	70	86	100	115	8	23	39	55	71	88	80
123	14	29	43	62	77	91	106	121	13	28	44	60	76	93
5	19	33	47	65	80	93	108	122	12	28	43	59	75	91
9	23	37	50	68	82	95	109	123	13	29	44	59	75	91
13	27	40	53	70	84	97	110	0	14	29	43	59	74	90
11	23	37	50	67	80	93	106	119	9	22	37	52	67	83
22	35	47	59	76	89	101	114	3	16	29	44	59	73	89
29	41	53	65	81	94	106	118	6	19	32	46	61	75	90
34	46	58	69	85	97	108	120	8	21	33	47	61	75	90
39	51	62	73	88	100	111	122	10	22	34	47	61	75	89
39	51	61	72	87	98	108	119	7	18	30	42	56	69	83
38	48	59	69	84	94	104	115	2	13	24	35	48	62	76
32	42	51	62	76	86	96	106	116	3	14	25	37	50	64
38	47	56	67	80	90	99	109	119	5	15	25	38	50	63
35	43	52	61	75	84	93	102	112	121	7	17	29	40	53
34	42	51	59	73	81	90	99	108	117	2	12	23	34	46
40	48	56	64	77	85	93	102	110	119	4	13	24	34	46
35	43	50	58	70	78	86	94	102	110	119	3	14	24	35
35	42	49	56	67	74	83	90	98	106	114	122	8	18	28

3

HYDROPHONE NUMBER

HYDROPHONE NUMBER

25	26	27	28	29	30	31	32	33	34	35	36	37	38
92	108												
92	108												
80	96												
93	109												
91	107												
91	107												
90	106												
83	99												
89	104												
90	106												
90	105												
89	104												
83	98	120											
76	90	112											
64	78	100											
63	77	99											
53	67	89											
46	59	81											
46	58	80	96										
35	47	69	85										
28	40	60	76	94									

4

UMBER

HYDROPHONE NUMBER

38 39 40 41 42 43 44 45 46 47 48 49 50 51

Figure 63. Sampling Times for Compromise Bean former Between the SSB(N) 598 and SSB(N) 608 Class Submarines (Sheet 1

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
22					120	3	9	16	22	29	35	42
23						5	11	18	23	30	36	42
24							19	25	30	36	42	48
25								20	25	30	36	41
26									26	32	37	42
27										32	37	42
28											39	43
29												53
30												
31												
32												
33												
34												
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												

2

HYDROPHONE NUMBER

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
35	42	49	56	66	73	80	88	95	103	110	118	4	13	23
36	42	48	55	65	71	78	85	93	100	107	114	123	8	17
42	48	54	60	70	76	82	89	96	103	110	116	1	9	1[illegible]
36	41	47	53	62	68	74	80	86	92	100	106	114	122	[illegible]
37	42	47	53	62	67	73	78	84	90	96	103	111	118	[illegible]
37	42	47	52	61	65	71	76	82	87	93	98	107	114	12[illegible]
39	43	46	53	62	66	71	76	81	87	92	97	104	112	11[illegible]
	53	57	62	70	74	79	83	88	93	98	102	109	116	12[illegible]
		59	63	71	74	79	83	87	92	96	100	106	111	11[illegible]
			66	73	76	81	84	88	92	96	100	105	109	11[illegible]
			69	76	79	83	87	90	94	98	101	106	110	11[illegible]
				83	86	90	94	97	101	104	107	112	115	11[illegible]
					91	95	98	102	105	109	112	116	119	12[illegible]
						100	104	107	111	114	117	121	0	[illegible]
							109	113	117	120	123	3	6	[illegible]
								113	117	121	0	3	6	[illegible]
									122	2	5	9	12	[illegible]
										12	15	19	22	[illegible]
											19	23	26	[illegible]
												21	24	[illegible]
													46	[illegible]

HYD[illegible]

3

HYDROPHONE NUMBER

HYDROPHONE NUMBER

4	25	26	27	28	29	30	31	32	33	34	35	36	37	38
13	23	34	54	70	88	105								
8	17	28	48	64	81	99	115							
9	13	29	48	64	81	99	115	7						
122	6	17	35	51	68	85	102	119	11					
118	2	12	30	46	63	80	96	114	6	22				
114	121	7	25	40	57	74	90	108	0	16	32			
112	119	4	21	36	53	70	86	103	120	12	29	45		
116	122	6	23	38	55	71	87	104	121	14	30	46	62	
111	118	1	17	31	47	64	79	96	112	6	22	38	54	71
109	114	122	12	26	42	58	73	90	106	123	15	31	47	64
110	114	120	10	23	39	54	68	85	100	116	9	25	41	58
115	119	0	13	26	40	55	69	85	100	116	8	24	39	56
119	122	3	15	27	40	54	67	83	98	113	4	20	35	51
0	3	8	19	30	43	56	69	84	98	113	3	19	34	49
6	9	13	24	35	47	60	72	87	101	115	6	21	35	51
6	9	13	24	34	46	58	70	84	98	112	2	16	31	40
12	15	19	29	38	50	62	73	87	100	114	4	18	32	47
22	25	30	38	47	58	70	81	94	107	120	10	23	38	58
26	29	34	42	51	61	72	83	96	108	121	10	23	37	5
24	27	31	40	48	58	69	79	91	103	116	4	17	30	4
46	49	53	60	68	77	88	97	109	121	9	21	33	47	5
	49	52	59	67	76	86	95	106	118	5	17	29	41	5
	57	60	67	74	83	92	101	112	123	10	21	32	44	5

4

UMBER

HYDROPHONE NUMBER

	38	39	40	41	42	43	44	45	46	47	48	49	50	51
62														
54	71													
47	64	85												
41	58	78												
39	56	76	91											
35	51	71	86	101										
34	49	69	83	98	114									
35	51	70	84	99	114	5								
31	46	65	79	93	108	123	13							
32	47	65	79	93	107	122	12	28						
38	52	70	83	97	111	1	15	31	44					
37	51	68	82	95	109	122	12	26	41	54				
30	44	61	74	87	100	114	3	17	30	44	58			
47	59	76	89	101	114	3	16	29	43	56	69	82		
41	54	70	82	95	107	120	8	21	33	47	60	72	85	
44	57	73	84	96	108	120	8	21	33	45	58	70	83	

Figure 63. Sampling Times for Compromise Beam-former Between the SSB(N) 598 and SSB(N) 608 Class Submarines (Sheet 2

HYDROPHONE NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11
45											
46											
47											
48											
49											
50											
51											
52											
53											
54											
55											
56											
57											
58											
59											
60											
61											
62											

2

HYDROPHONE NUMBER

11 12 13 14 15 16 17 18 19 20 21 22 23 24

3

HYDROPHONE NUMBER

HYDROPHONE NUMBER

24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
		67	73	80	88	97	105	116	2	13	24	35	46	
		74	[illegible]	86	94	102	110	120	6	16	27	37	48	
		83	89	95	102	110	117	3	12	22	32	42	52	
		91	97	103	109	117	0	9	18	27	37	46	56	
		92	98	103	110	117	123	8	16	25	34	44	53	
		102	108	113	119	2	8	16	24	32	41	50	59	
			115	120	2	8	14	21	29	37	45	54	62	
			119	0	5	11	16	23	31	38	46	54	62	
			119	0	5	10	15	22	29	36	43	51	59	
			116	120	0	5	10	17	23	30	37	44	52	
			116	120	0	5	10	16	22	28	35	42	49	
			119	123	3	7	12	17	23	29	35	42	48	
			117	121	0	5	9	14	19	25	31	37	43	
			119	123	2	6	10	15	20	26	31	37	43	
			123	5	8	11	15	19	24	29	34	39	45	
			109	114	17	20	24	28	32	36	41	45	51	
			123	3	6	9	37	40	44	48	52	56	61	
			121	2	16	19	23	48	53	57	60	64	68	

4

YDROPHONE NUMBER

HYDROPHONE NUM

	37	38	39	40	41	42	43	44	45	46	47	48	49	50
35	46	58	74	85	96	108	120	7	19	31	43	55	67	79
37	48	60	75	86	97	108	119	6	18	29	40	52	64	76
42	52	64	78	89	99	110	121	8	19	29	40	51	63	74
46	56	67	81	91	101	112	122	8	19	29	40	50	60	72
44	53	63	77	87	96	106	116	2	12	22	32	42	52	62
50	59	68	82	91	100	110	119	5	14	24	33	43	52	62
54	62	71	84	93	102	111	120	5	14	23	32	41	50	60
54	62	70	83	92	100	109	117	2	10	19	28	36	45	54
51	59	66	78	87	95	103	111	119	3	12	20	28	36	45
44	52	59	70	77	85	93	101	109	116	0	8	16	24	32
42	49	55	66	73	80	88	96	103	110	118	1	9	16	24
42	48	55	65	72	78	85	92	100	106	114	121	4	11	18
37	43	49	59	66	72	78	85	91	97	105	112	119	1	8
37	43	48	58	64	70	76	82	88	94	101	108	114	120	3
39	45	49	58	64	69	75	80	86	91	97	102	109	115	120
45	51	55	63	68	73	78	83	88	92	98	103	108	114	119
56	61	64	72	77	81	86	90	94	98	103	108	112	118	122
64	68	71	78	83	86	90	94	98	101	105	109	113	117	122

Figure 63. Sampling Times for Co
former Between the S
SSB(N) 608 Class Subm

5

HYDROPHONE NUMBER

46	47	48	49	50	51	52
31	43	55	67	79	95	
29	40	52	64	76	91	
29	40	51	63	74	89	
29	40	50	60	72	87	
22	32	42	52	62	77	
24	33	43	52	62	77	
23	32	41	50	60	73	83
19	28	36	45	54	67	76
12	20	28	36	45	57	56
0	8	16	24	32	44	52
118	1	9	16	24	35	43
114	121	4	11	18	29	37
105	112	119	1	8	19	26
101	108	114	120	3	13	20
97	102	109	115	120	6	12
98	103	108	114	119	5	10
103	108	112	118	122	7	12
105	109	115	117	122	6	10

Figure 63. Sampling Times for Compromise Beamformer Between the SSB(N) 598 and SSB(N) 608 Class Submarines (Sheet 3)

SECTION IV

CONCLUSIONS

1. VERTICAL BEAM COVERAGE STUDY

It is difficult to make a clear-cut decision as to whether vertical beam broadening and depression are beneficial to the overall detection problem. For noisy targets, such as a snorkler, the detection range is improved somewhat by beam depression. For quiet targets, such as the Permit submarine, the detection range may be impaired. Beam depression and vertical beam broadening is effective only in cases where array gain for surface duct reception can be sacrificed at the expense of improved bottom bounce reception. This trade-off can be costly in terms of detectability of quieter targets.

It is evident that any conclusions are very sensitive to the characteristics of the model. Whereas one set of specified inputs might dictate a certain degree of beam depression and broadening, this might be detrimental to target detectability for another set of inputs. To assure the detectability of quiet targets with the array gain provided by the BQR-7 DIMUS, it appears that vertical beam broadening and depression is not desirable.

2. COMPROMISE BEAMFORMER FEASIBILITY STUDY

Several of the classes of submarines are quite compatible for the purpose of designing a suitable compromise beamformer. Chief candidates for a suitable two-array compromise are the following pairs.

SS(N) 594 and SSB(N) 608
SSB(N) 608 and SS(N) 671

Degradation of the peak response for most beams is less than 0.2 dB utilizing these pairings. The least desirable combinations for a two-array compromise are the following pairs.

SSB(N) 598 and SS(N) 671
SSB(N) 598 and SSB(N) 608

The degradation for these pairings is considered unnecessarily large when compared to other two-array compromises.

The largest degradation for the three-array and four-array compromises which were considered in Section III are approximately 0.5 and 0.8 dB, respectively.

If a peak loss of 0.8 dB due to the effects of compromising the delays is considered acceptable, the four-array compromise is suitable. If a peak loss in the vicinity of 0.5 dB is acceptable, a three-array compromise between the SS(N) 594, SSB(N) 598, and the SSB(N) 608 is recommended. If both of these degradations are excessive, the best pair of two-array compromises which include all four classes of submarines is the following.

SSB(N) 608 and SS(N) 671

SS(N) 594 and SSB(N) 598

The largest degradation for these pairings is approximately 0.3 dB.

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